THE MICROCLIMATE OF NARROW AND WIDE ROW SORGHUM WITH EQUAL PLANT DENSITY

by 1050 710

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B.Sc., Ahmadu Bello University, 1972

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1974

Approved by:

Major Professor

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ACKNOWLEDGEMENT

This study was carried out during the summer of 1973 at the Kansas State University Ashland Agronomy Farm near Manhattan, Kansas. It was financed by the Agency for International Development under a contract with Ahmadu Bello University, Zaria, Nigeria.

I am grateful for the guidance and useful advice given by my major advisor, E. T. Kanemasu. In addition, my special thanks go to J. Y. Yayock and E. W. Chin Choy for their useful suggestions and much needed, moral support during the initial stages of the experiment. C. Hiebsch put in long hours of assistance during the data collection period. Mary Dawson re-produced all the graphs prior to photo-copying.

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LIST OF SYMBOLS

		UNIT
C	- heat capacity of the soil	cal.gm^{-1}.deg^{-1}
Cp	- specific heat of air	cal.gm^{-1}.deg^{-1}
D	- displacement parameter due to vegetation	cm
E_a	- energy derived from advection	cal.cm^{-2}.min^{-1}
E_s	- evaporative energy flux	cal.cm^{-2}.min^{-1}
E_T	- energy flux due to transpiration	cal.cm^{-2}.min^{-1}
F	- conversion factor from ppm to g.cm^{-3}	dimensionless
G	- soil heat flux	cal.cm^{-2}.min^{-1}
H	- sensible heat flux	cal.cm^{-2}.min^{-1}
K	- exchange coefficient	cm^2.sec^{-1}
K'	- thermal conductivity	cal.cm^{-1}.sec^{-1}.deg^{-1}
K_C	- exchange coefficient for CO_2	cm^2.sec^{-1}
K_H	- exchange coefficient for heat	cm^2.sec^{-1}
K_W	- exchange coefficient for water vapor	cm^2.sec^{-1}
L	- long wave radiation	cal.cm^{-2}.min^{-1}
LAI	- leaf area index	dimensionless
LE	- latent heat flux	cal.cm^{-2}.min^{-1}
L	- leaf water potential	bars
NCE	- net carbon dioxide exchange	mg.dm^{-2}.hr.$^{-1}$
NIR	- near infrared radiation	nanometers
P	- atmospheric pressure	mbars
PAR	- photosynthetic active radiation	nanometers
PR	- energy stored by the crop and photochemical energy	cal.cm^{-2}.min^{-1}

P_S	- net photosynthetic rate	$g(CO_2).cm^{-2}.sec^{-1}$
R_A	- diffuse sky radiation	$cal.cm^{-2}.min^{-1}$
R_G	- direct solar radiation	$cal.cm^{-2}.min^{-1}$
Ri	- Richardson's number	dimensionless
R_K	- reflected solar radiation	$cal.cm^{-2}.min^{-1}$
R_n	- net radiation above the crop	$cal.cm^{-2}.min^{-1}$
Rn'	- net radiation below crop canopy	$cal.cm^{-2}.min^{-1}$
R_S	- solar radiation	$cal.cm^{-2}.min^{-1}$
R_T	- reflected and emitted thermal radiation	$cal.cm^{-2}.min^{-1}$
S	- $\Delta e / \Delta T$	$mbars. deg^{-1}$
T	- temperature	deg.C
T_a	- air temperature	deg.C
T_c	- crop temperature	deg.C
V	- wind speed	$cm.sec^{-1}$
d	- zero plane displacement	cm
e	- water vapor pressure	mbars
e*	- saturation vapor pressure	mbars
g	- acceleration of gravity	$cm.sec^{-2}$
k	- von Karman constant	dimensionless
r_a	- boundary layer resistance	$sec.cm^{-1}$
r_m	- mesophyll resistance	$sec.cm^{-1}$
r_s	- stomatal resistance	$sec.cm^{-1}$
Z	- height above ground	cm
Z_o	- roughness parameter	cm
γ	- psychrometric constant	dimensionless
ϵ	- ratio of the molecular weight of water to the molecular weight of air	dimensionless

λ	- heat of vaporization of water	$cal.gm^{-1}$
ρ	- air density	$gm.cm^{-3}$
φ	- diabatic influence function	dimensionless
Φ	- integral diabatic influence function	dimensionless

INTRODUCTION

Crop growth is known to result from a complex interaction of nutrients and water from the soil, carbon dioxide from the air, and light energy from the sun. Thus, for growth and development, plants depend on their genetic composition and on the environmental conditions of soil and climate.

In a bid to improve crop yield, man has exploited the genetics of the species to an extent where significant gains, for the major crops, along this line is not readily obtained. The complexity of the system requires a deeper understanding of all the environmental factors that are known to influence the growth of the crops.

Mitchell (1970) classified factors limiting crop growth into two: (1) those that detract from the yield potential such as weeds, insects and diseases; and (2) those that add to the yield potential and thus affect yield ability such as nutrients, stand densities, leaf orientation and row width. With the recent availability of sophisticated instrumentation, a probe into the microclimate of the crop may open yet another headway.

The major bulk of microclimatological work reported in the literature is on the corn crop. Among the few recent studies on sorghum are those of Chin Choy and Kanemasu (1974) on the energy balance of wide-and narrow-row sorghum with equal linear plant density; Szeicz, et al. (1973) on the stomatal factor in the water use and dry matter production by sorghum; and Hanks, et al. (1972) on soil-plant-water-microclimate relationships of wide-row grain sorghum in the Central Great Plains.

These studies, along with many others (e.g. Stickler, 1964; Blum, 1970), indicate that when soil moisture is not limiting, higher water use efficiency and grain yield could be obtained with closer row spacing. Chin Choy and Kanemasu (1974) reported that seasonal evapotranspiration was about 10% more from wide rows than from narrow-row sorghum and suggested that this higher rate for the wide rows was due to row advection during the early part of the growing season and large scale advection during the latter part of the growing season. It was, however, impossible to specify whether the difference in evapotranspiration between the wide and narrow rows was due to physical spacing or the higher plant population in the narrow rows providing a better soil cover.

The goals of this experiment were: 1) to compare the radiation and energy balance of narrow- and wide-row sorghum with emphasis on:

a. the effectiveness of the planting patterns in intercepting visible and near infrared radiations and providing a crop cover to reduce water loss from the soil,

b. the partitioning of net radiation into the component terms of the energy balance equation,

c. the comparison of evapotranspiration (LE) values estimated by the resistance, lysimetric, and combination methods for both the narrow and wide-row plots;

and 2) to accumulate a complete set of microclimatic and plant data for narrow- and wide-row sorghum of equal plant density--comprising of:

a. an in-depth study of the temperature and vapor pressure regimes within and above the crop canopies, and

b. an examination of the leaf water potential and stomatal diffusion resistance of the canopies as an aid to compiling the true plant moisture picture.

The study is of interest to agronomists because of possibilities of controlling the microclimate and thus influencing photosynthesis and evapotranspiration through cultural means. A basic understanding of the energy balance processes within different planting patterns may also be useful in man's effort to achieve greater and more economical crop production.

GENERAL CONDITIONS OF THE EXPERIMENT

The experiment was conducted on the Kansas State University Ashland Agronomy Farm located 14 km southwest of the University. The elevation is about 350m above sea level.

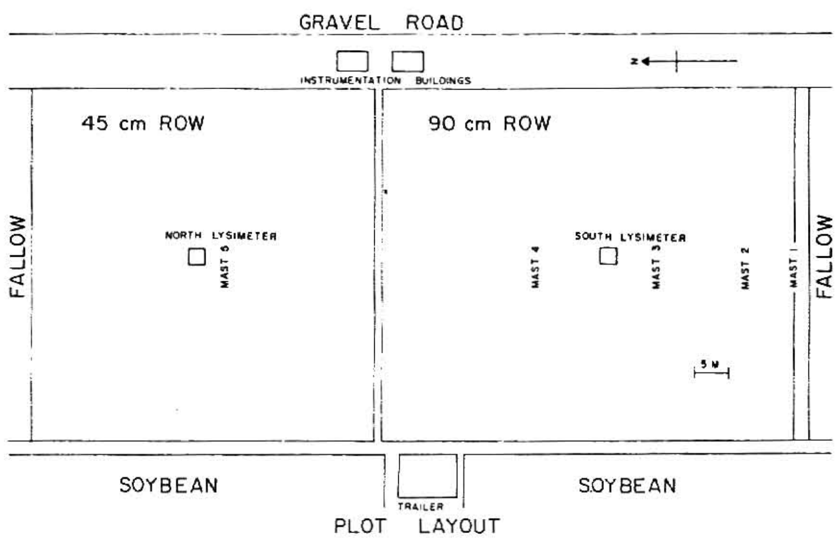
The layout of the experimental site in shown in Fig. 1. The cropped area, measuring 2 ha, was divided into two--the north plot with .45m row width and the south plot with .90m row width. The plots were bordered to the east by a gravel road, to the west and north by irrigated experimental plots sown to soybean; and to the south and north by two large fields left to fallow. There are no trees within 100m of the plots. A trailer and two small sheds on the east and west sides of the plots, respectively, housed the data acquisition equipment.

Both plots were fertilized at a rate of 50 kg of nitrogen per ha (anhydrous ammonium nitrate). Sorghum bicolor (L.) Moench was planted on June 1, 1973 at an equal population of about 104,000 plants per ha for both the narrow and wide row plots with rows orientated in N-S direction. During the growing season, both plots were irrigated six times (June 12, 18, 22, 28, August 7 and 28).

All the measurements were taken during the growing season--spanning the period of June 7 to September 15th. Continuous scanning of all sensors were made every minute during the day (every 5 minutes at night) and a calculator, on line, computed 30 minute averages during the day and hourly

Fig. 1

Layout of research field



averages at night. The averages were printed out on a teletype printer. A summary of the weather conditions throughout the growing season is given in Appendix A.

A weighing lysimeter (2 x 2 x 1½m) is located in the center of each plot. The evapotranspiration rates, calculated by the above method, are accurate to within 0.05mm of water.

CHAPTER I

RADIATION BALANCE AND LIGHT INTERCEPTION

The incoming solar radiation above the crop (R_S) is a sum of the direct solar radiation (R_G) and diffuse sky radiation (R_A).

$$R_S = R_G + R_A \quad (1.1)$$

R_S is either reflected from the leaves, transmitted through the crop canopy, or absorbed by the leaves and the soil. Reflected solar radiation is

$$R_K = aR_S \quad (1.2)$$

where a is albedo of the crop surface or the reflectance for solar radiation. The total upward radiation is

$$R = R_K + R_T \quad (1.3)$$

where R_T is the reflected and emitted thermal radiation. The proportion of R_S that is reflected or transmitted would depend on soil properties, amount and type of cloud cover, the sun's angle during the day, leaf arrangement and moisture status, and density of crop cover (Monteith and Szeicz, 1961; Monteith, 1965; Blad and Baker, 1972).

Net radiation, Rn, is the net flux density of all downward and upward radiation.

$$Rn = L\downarrow + R_S - L\uparrow - aR_S \quad (1.4)$$

where $L\uparrow = \sigma T_s^4 + (1 - \epsilon) L$; L represents the flux of longwave radiation; ϵ is the emissivity; σ is the Stefan Boltzman constant; and T_s is the surface temperature.

The radiation regime in the crop can be divided into visible or photosynthetic active radiation (Allen, 1973), near infrared (NIR), and thermal regions of the spectrum. Photosynthetic active radiation (PAR--400 to 700nm) is the spectral range most important to the agronomist. PAR supplies the excitation energy to the chlorophyll molecule for photosynthesis (about 50% of direct solar radiation when the sun is overhead) and determines, to a large extent, the width of stomatal aperture.

The reflectivity of leaves vary with wavelength. It is minimum in the blue (400 - 510nm) and red (610 - 710nm) portions of the spectrum since these wavebands are strongly absorbed by chlorophyll. Wavelengths between 510 - 610nm have relatively high reflectance--giving the green color to vegetation. Reflectivity of a leaf is maximum at the NIR (Sinclair, Hoffer and Schreiber, 1971). High leaf reflectance of NIR is hypothesized to occur in the mesophyll tissue (Sinclair, Schreiber and Hoffer, 1973). The tissue contains media of differing refracture indices, large intercellular spaces, cells with irregular structure and cell walls orientated at virtually all angles--conditions necessary for critical reflectance.

Generally, the visible reflectance of vegetation is lower than its total albedo. For example, the reflectivity of a corn crop may vary from 40 percent in the NIR (Yocum, Allen and Lemon, 1964; Sinclair, 1971; Kalma and Badham, 1972) to 7 percent in the visible spectrum (Sinclair, et al., 1973), while the albedo is about 20 percent. Reflectivity also varies with the stage of crop development (Gausman, Allen, Schupp, Wiegand, Escobar and Rodriguez, 1970; Gausman, et al., 1973); it is low at the early stage and increases as a function of crop cover.

Literature is limited on the light interception and radiation balance of narrow- and wide-row sorghum. The reported albedo of wide-row (1m) sorghum range from 0.15 to 0.19 (Szeicz, et al., 1973; Brown, 1964; Hanks, Gardner, Allen, Wooley, Gardner, Fritschen, Lemon and Aase, 1972). Predicted light interception within 1m rows of sorghum, using a light model applied to N-S rows, was about 44% (Allen, 1973). This study focused at comparing the radiation balance and light interception of wide- and narrow-row sorghum.

MATERIALS AND METHOD

Solar and Net Solar Radiation

A pyranometer (Eppley model #8-48)[1] measured incoming solar radiation. Net solarimeters (Swissteco Type SW-1)[2] were used to measure net solar radiation above the two plots. These sensors were extended from a platform erected at a height of about 2.5m above the ground (approximately 1.5m above the crops at maturity).

Net Radiation Above and Below the Crop

Net radiation flux densities above (Rn) and below (Rn') the crop were measured with Fritschen-type, polythene-shielded net radiometers (Thornthwaite model # 603)[3] and 2 pairs of 1m-long, net linear radiometers,[2] respectively. The net radiometers were set at 2.5m above the ground while the net linear radiometers were placed across two rows below the crop canopy (2 in each plot). The shields of these sensors (both types of net radiometers) were kept inflated and internally dry by 2 small aquarium pumps

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[1]Eppley Lab., Newport, R.I.

[2]Swissteco Pty. Limited, 26 Miami Street, Hawthorne, Victoria, Australia.

[3]C. W. Thornthwaite Assoc., Centerton, N. J.

blowing air through a silica gel container. They were wiped clean every morning and pulled apart to dry after every rain when moisture tended to condense within the shields.

Photosynthetic Active Radiation (PAR)

Incoming visible light was measured with a quantum sensor (Lambda LI-1905)[4] at a height of 2.5m above the ground. Transmitted PAR and PAR reflected off the soil were measured with 2 sets of light sensors (each set consisting of 5 sensors connected in parallel) mounted on a bar below the canopy and normal to the rows. Towards the end of the season, 3 light sensors mounted on a traversing platform (pulley operated and travelling at a rate of 2 cm/sec) were lowered below the canopy to measure PAR transmitted through the canopy and reflected off the soil.

Near Infrared Radiation (NIR) Above and Within Canopies

Measurements were made with silicon photocells (Sharp, SBC 255)[5] filtered with a Wratten 88A filter; therefore, the sensors were responsive to the 700 to 1100nm waveband. The sensors were positioned to measure incoming, reflected and transmitted NIR radiation on both plots.

Spectral Reflectance

Incoming and reflected light in the 410, 450, 500, 545, 600, 655 and 750 nonometer wavelengths (40 to 80nm waveband) were measured by upward and downward positioning of the sensor head of a spectral radiometer (Lambda model #LI-187)[4] mounted at a height of about 2m above the ground. All spectral measurements were made between 1300 and 1500 hours on clear days only.

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[4]Lambda Instruments Co., Inc., Lincoln, Nebraska.

[5]Sharp Electronics Corp., Carlstadt, N. J.

Data Collection

Continuous scanning of wet and dry-bulb temperature, soil temperature, radiation sensors, and lysimeters were made every minute during the day and every 5 minutes at night with a data acquisition system (Newlett Packard model #2012 B). A calculator (Hewlett Packard model #9820 A) on line, computed 30 minute averages of air temperature, vapor pressure, soil temperature, energy, and radiation balance components during the day and hourly averages at night. The averages were printed out on a teletype printer (ASR 35).

Plant Data

Table 1.1 shows the growth stages (according to Vanderlip and Reeves, 1972) for both sorghum plots. Leaf area indices (LAI) were about equal for both narrow and wide rows throughout the growing season (Fig. 1.1). LAI was slightly higher in the wide rows during the early and later parts of the season. By July 15, leaves from adjacent rows had overlapped in the narrow rows while gaps of about 15 cm-width still existed between rows in the 90 cm plot.

Crop height, taken around the temperature and vapor pressure profile-measuring masts, is presented in Table 1.2 for July 12, 30 and August 6. In general, the leaves were concentrated within 40 and 85 cm height above the ground on both plots.

Table 1.1

Growth Stages of Sorghum Crop in Both Plots

Stage	Date	Identifying Characteristics
0	June 8	Seedling emergence.
1	June 15	Plant height 8-12 cm; 3 leaves present.
2	June 25	Crop height 25 cm; 5th leaf appeared.
3	July 5	Canopy closed in narrow row-plot; about 8 leaves per plant.
4	July 13	8-9 collar leaves/plant.
5	July 20	Head extended into flag leaf.
6	July 30	Head fully emerged from boot.
7	August 10	Soft dough stage.
8	August 20	Sorghum heads turning red.
9	September 2	Physiological maturity.

Fig. 1.1

Seasonal LAI for narrow and wide row sorghum

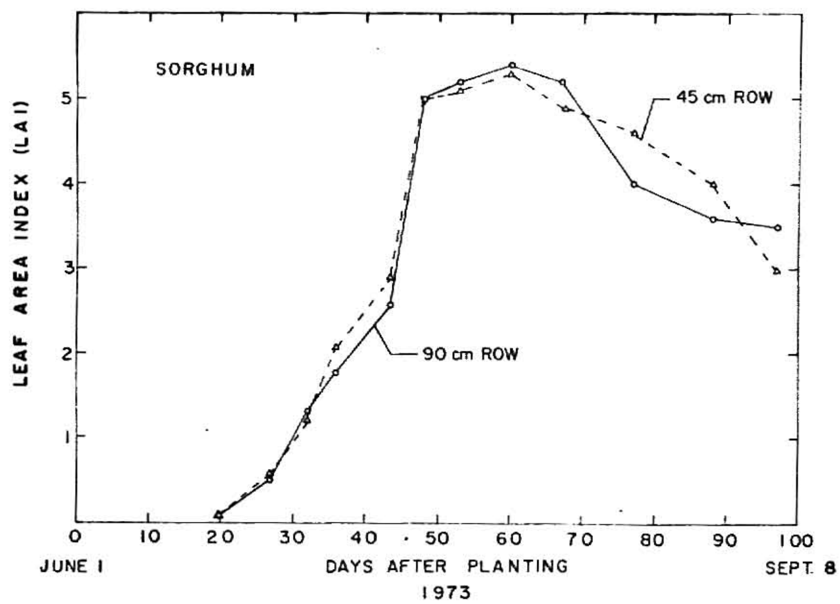


Table 1.2

Crop Height (cm) of sorghum at each of the 5 mast locations

Masts	1	2	3	4	5
July 12	80	79	80	80	85
July 30	109	109	114	108	110
August 6	124	131	128	130	130

RESULTS AND DISCUSSION

Table 1.3 shows the daily averages of percent PAR, NIR and albedo above the two plots for 8 days during the growing season. Visible and near infrared light reflected from the narrow rows were consistently higher than from the wide rows. Reflectance of visible light averaged 5% and 4.7% for the narrow and wide rows, respectively and showed an increase in reflectance as the season progressed. NIR radiation is less readily absorbed by green leaves (Allen and Richardson, 1968) and much of the incoming NIR radiation was, therefore, reflected. The proportion reflected was highest when LAI was maximum and averaged 41.7% in the narrow rows and 28.5% in the wide rows for the days considered.

Figs. 1.2 and 1.3 show the daily variations of percent visible and NIR reflected for both plots. The lowest reflectivity on these graphs and the lowest albedo during the day (Fig. 1.4) occurred about midday. Similar observation made by Monteith (1959), Kalma and Stanhill (1969) and Fuchs, et al. (1972) was explained as due to diurnal changes of the properties of incident solar radiation such as solar elevation, spectral composition, diffuse-to-direct ratio and flux density. It may also be related to the clumped distribution of sorghum leaves (Nilson, 1971). Leaves arise from alternate sides of the stalk and tend to fall in the same vertical plane. There is, therefore, much mutual shading by the leaves especially when the solar beam is directly overhead. At noon, when solar elevation is greatest, soil exposure is also maximum.

The average seasonal albedo was 0.18 for the wide rows and 0.20 for the narrow rows. These values agree well with the 0.15 obtained by Hanks, et al. (1972) and Szeicz (1973) over wide-row sorghum. Albedo was highest

Table 1.3

Daily averages of percent PAR and NIR reflected from narrow and wide-row sorghum

	NARROW			WIDE		
Days	PAR	NIR	Albedo	PAR	NIR	Albedo
July 12	4.6	42.9	.22	4.2	28.6	.19
13	4.6	43.6	.23	4.2	29.4	.19
25	4.7	49.3	.22	4.3	30.1	.18
26	4.7	46.4	.21	4.3	30.3	.19
August 16	5.0	38.4	.18	4.4	30.4	.16
20	5.5	38	.19	4.7	26.8	.18
25	6.0	37.8	.20	5.2	25.8	.19
26	6.1	37	.19	5.4	25.9	.18

Fig. 1.2

Percent reflectance of PAR and NIR on July 13

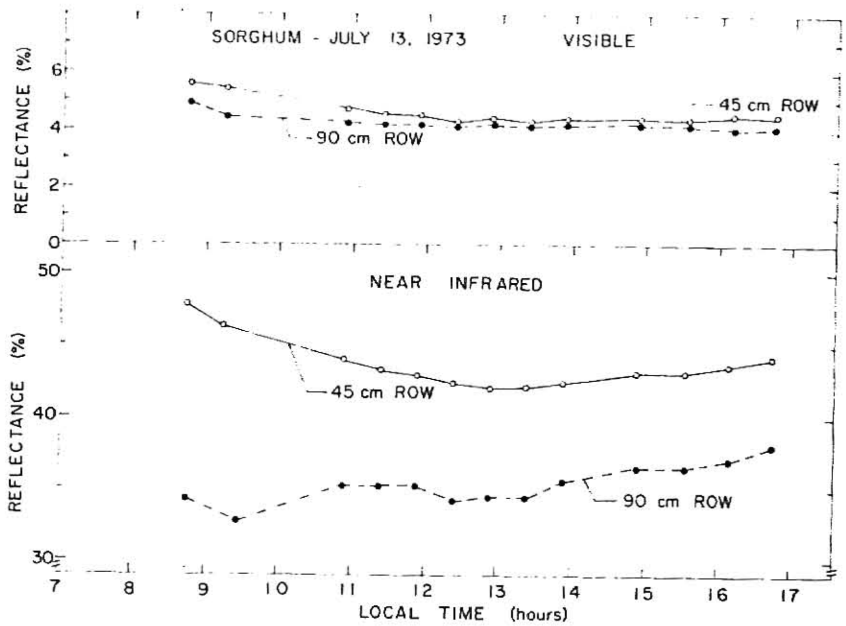


Fig. 1.3

Percent reflectance of PAR and NIR on August 16

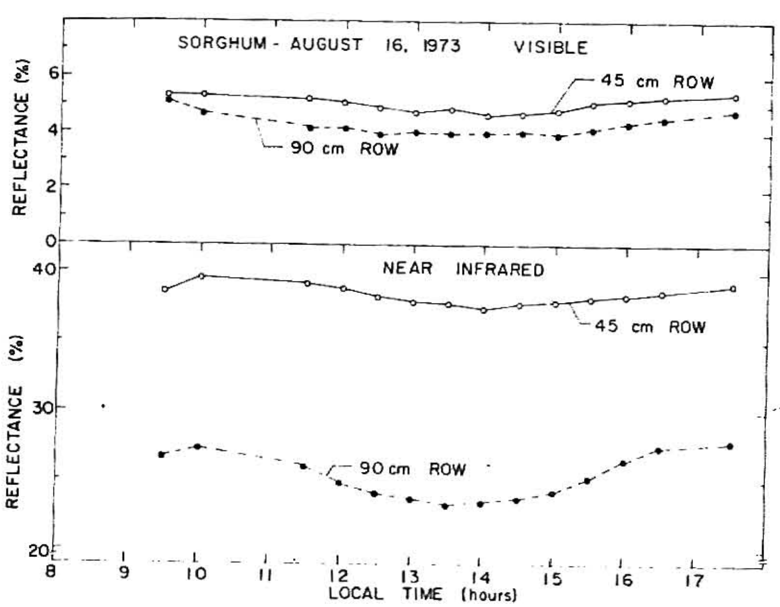


Fig. 1.4

Diurnal albedo for 3 days during the season

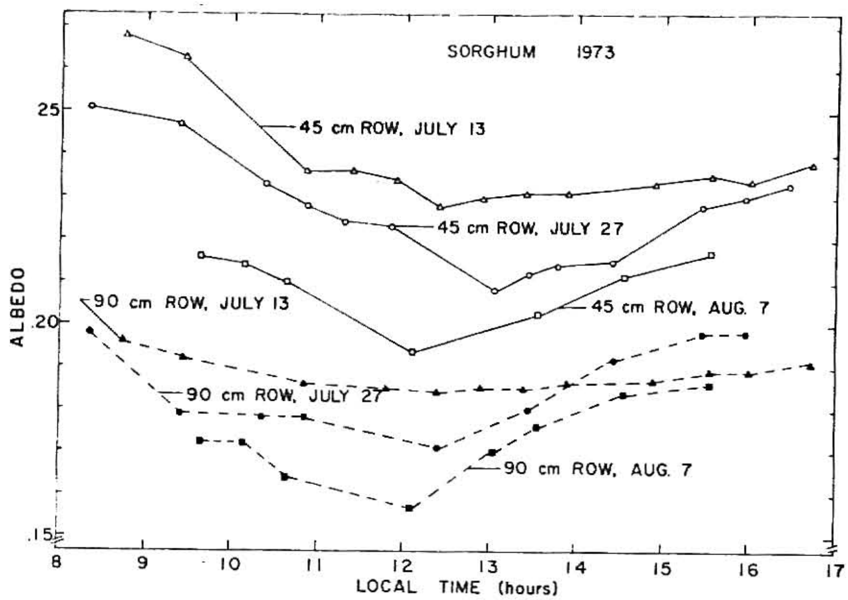
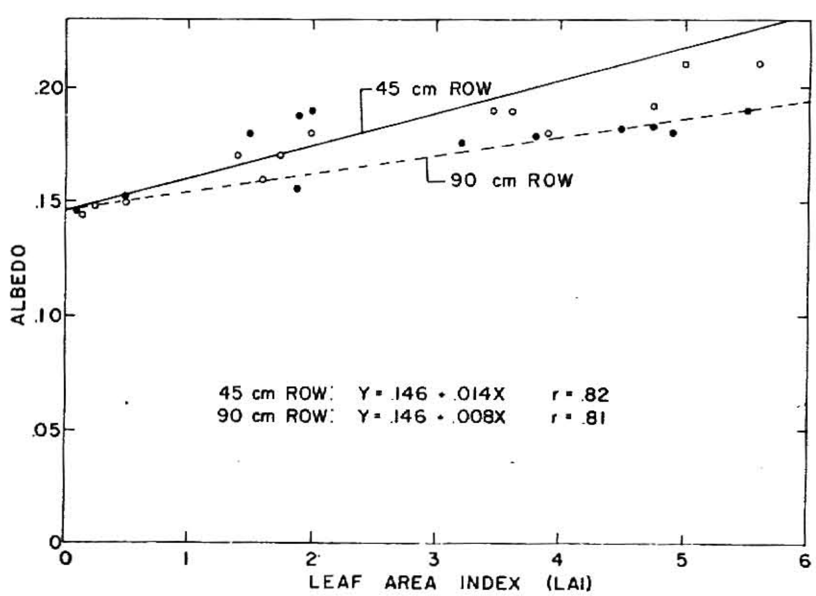


Fig. 1.5

Relationship between albedo and LAI



about July 13 (narrow row 0.23; wide row 0.19) when LAI in the plots was about maximum; and lowest about August 16 when crop cover had decreased. Even though LAI were about the same on both plots throughout the season, the narrow rows consistently gave higher albedo. This is due to differences in percent plant cover on the plots. The variation in albedo for the season, within each plot, was small and resulted mainly from LAI changes (Fig. 1.1).

When albedo was plotted against LAI (Fig. 1.5), the data were scattered but a slight increase of albedo with rising LAI was evident. The linear regression equation calculated was $Y = .146 + .014X$ ($r = .82$) for the narrow rows and $Y = .146 + .008X$ ($r = .81$) for the wide rows where Y is albedo and X is LAI. Soil albedo was .146. The rate of increase in albedo for a given rise in LAI was almost twice as high on the narrow rows than in the wide rows. Since LAI and climatic conditions were similar, the difference in albedo above the plots must be attributed to differences in plant cover.

Spectral reflectance for 4 days in the growing season was plotted for the narrow and wide rows (Fig. 1.6 and 1.7). Although LAI was highest on both plots about July 15, maximum plant cover occurred much later especially in the wide rows. Maximum reflectance at 750nm for narrow and wide rows occurred on July 15 (Fig. 1.7) and August 29, respectively. However, Table 1.3 shows the highest percentage of NIR reflected from the narrow and wide rows was on July 25 and August 16, respectively. The apparent inconsistency is presumably due to the differences in wavebands between the spectroradiometer (40 to 80nm) and the NIR sensor (300 to 400nm).

By August 29, plant cover on both plots had declined and the soil surface was very wet (both plots irrigated with 5 cm of water a day earlier); these conditions promote a lowering of the reflectance (Nkemdirim, 1972).

Fig. 1.6

Spectral reflectance from the narrow row sorghum

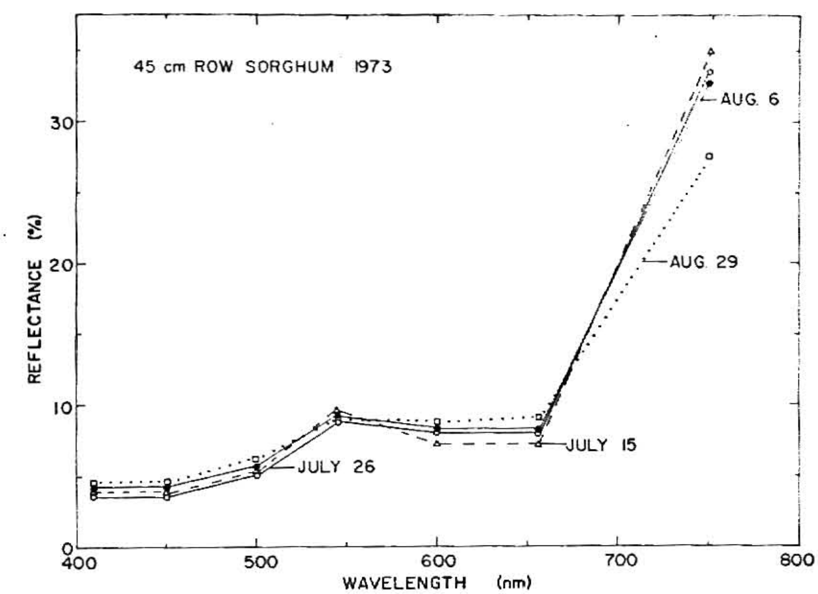
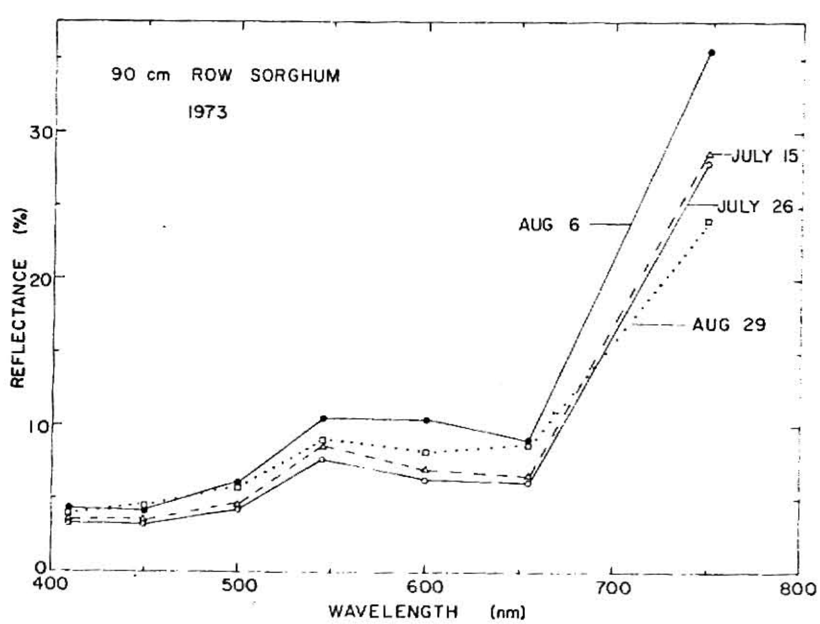


Fig. 1.7

Spectral reflectance from the wide row sorghum



In general, blue light (400-500nm) was least reflected. Reflectance increased at the 500 to 600nm range (green and yellow light) and decreased at the 600 to 650nm region (red light) before a large increase at 750nm. Reflectance was about the same for both plots within the blue and red portions of the spectrum.

During July, PAR transmitted through the crop canopy represents 3.8 and 25% of the incoming PAR in the narrow and wide rows respectively (Table 1.4); while PAR reflected from the soil back to the crop was 0.8% and 3.2% in the same order. Intercepted PAR was obtained by subtracting PAR transmitted through the canopy and PAR reflected by the crop from incoming PAR and PAR reflected from the soil. While intercepted PAR in the narrow rows was similar for July 16, 27 and August 26 (Fig. 1.7), it exhibited an increasing trend in the wide rows although LAI was decreasing during the same period.

Rn', the net radiation below the crop canopy, represents the difference between total radiation transmitted through the crop and that reflected and emitted by the soil; it is radiation absorbed by the soil and influences soil temperature and evaporation. The ratio, Rn'/Rn, given in Table 1.5, indicates the relative magnitude of net radiation at the soil surface. This ratio was 1 on June 7 when the plants were just emerging (light interception virtually zero), and declined as crop cover increased on both plots and reached a minimum between August 7 and 16. Near crop maturity, the ratio increased (Fig. 1.9A). Fig. 1.9B shows an exponential relationship between the fractional net radiation at the soil surface, Rn'/Rn, and LAI. The results agree closely with the relationship developed by Ritchie and Burnett (1971) for sorghum and cotton. The equations for the curves were:

Table 1.4

Percent of incoming visible light reflected off the crop (R), reflected off the soil (R(soil)), transmitted through (T) and intercepted by narrow and wide row sorghum

	NARROW ROW				WIDE ROW			
Days	R	T	R(soil)	Interception	R	T	R(soil)	Interception
July 13	4.6	4.7	1.3	92	4.2	37	4.8	63.6
16	4.8	3.1	1.0	93.1	4.0	28	3.1	71.1
17	4.7	3.6	0.5	92.2	4.3	20	3.0	88.7
26	4.7	3.7	0.5	92.1	4.0	15	1.7	82.7

Fig. 1.8

Diurnal interception of PAR for 3 days during the season

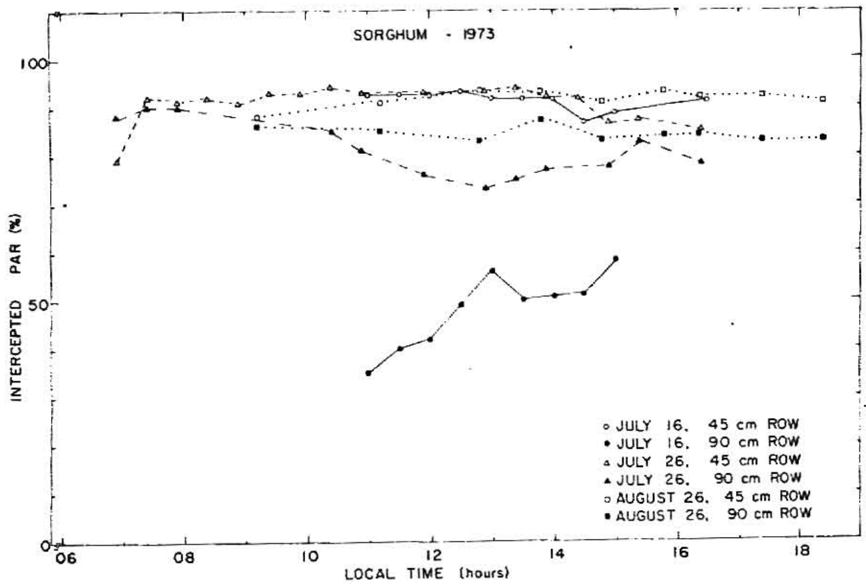


Table 1.5

Midday net radiation above and below narrow and wide-row sorghum cal/cm^2/min

		NARROW ROW				WIDE ROW			
Day	R_S	Rn	Rn'	Rn'/Rn	1-(Rn'/Rn)	Rn	Rn'	Rn'/Rn	1-(Rn'/Rn)
July 12	1.189	1.03	.319	.31	.69	.976	.421	.43	.57
15	1.338	1.084	.267	.25	.75	1.131	.424	.37	.63
18	1.009	.911	.185	.20	.80	.859	.297	.35	.65
25	1.163	1.016	.347	.34	.66	.984	.419	.43	.57
26	1.187	.976	.141	.14	.86	.986	.306	.31	.69
31	0.911	.751	.114	.15	.85	.741	.218	.29	.71
Aug. 1	0.951	.750	.118	.16	.84	.778	.214	.28	.72
6	1.095	.923	.139	.15	.85	.914	.227	.25	.75
7	1.140	.968	.120	.12	.88	.964	.226	.23	.77
11	1.138	.991	.192	.19	.81	.995	.356	.26	.74
16	1.075	.998	.218	.22	.78	.983	.162	.16	.84
20	1.036	.945	.278	.29	.71	.939	.246	.26	.74
25	0.959	.938	.192	.20	.80	.907	.289	.32	.68
26	0.990	.941	.120	.13	.87	.906	.270	.30	.70

Fig. 1.9

A) Fractional net radiation, Rn'/Rn, throughout the season
B) Relationship of Rn'/Rn with LAI

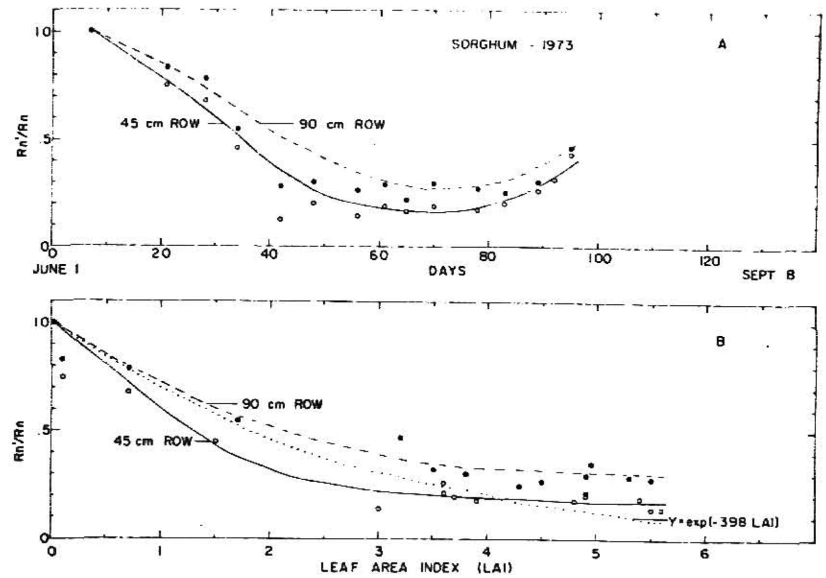
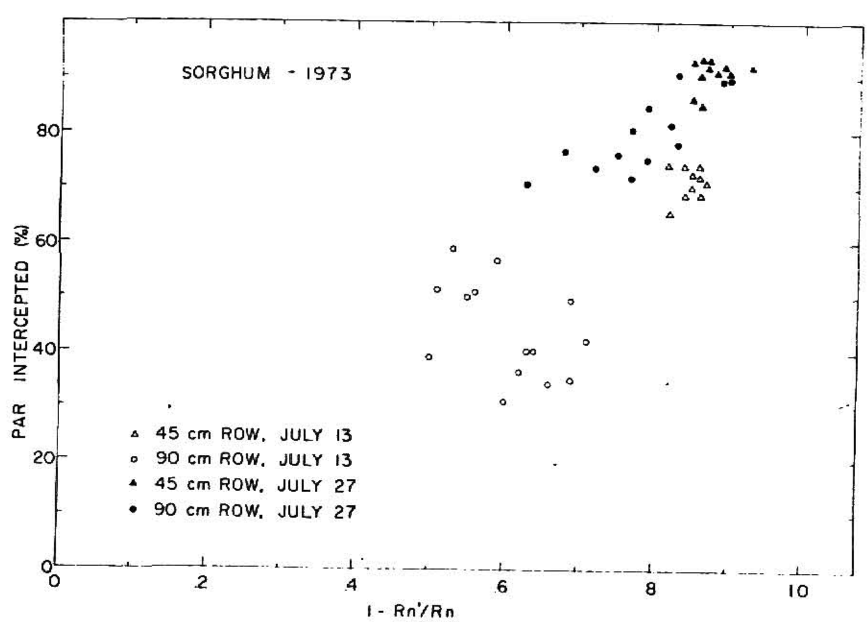


Fig. 1.10

Intercepted PAR vs. 1-(Rn'/Rn)



$$\text{narrow rows} - Y = \text{exponential } (-.310 \text{ LAI}) \quad (1.5)$$

$$\text{wide rows} - Y = \text{exponential } (-.241 \text{ LAI}) \quad (1.6)$$

where Y is $^{Rn'}/_{Rn}$.

Rn was about equal for the plots throughout the season. Rn' was almost always higher in the wide rows. Hourly values of $1-(^{Rn'}/_{Rn})$ were compared with PAR intercepted in July (Fig. 1.10). There was no definite relationship between PAR intercepted and $1-(^{Rn'}/_{Rn})$.

SUMMARY

Radiation and light interception measurements were made in the visible (400-700nm) and near infrared (700-1100nm) regions of the spectrum. The narrow rows reflected and intercepted more PAR than the wide rows. More PAR was transmitted through the wide-row canopy. Reflected PAR and NIR were 5% and 41.7%, respectively, in the narrow rows as compared to 4.7% and 28.5% obtained for the wide rows. (Table 1.3). Percent PAR intercepted during July was 92 for the narrow rows and 77 for the wide rows (Table 1.4). Total radiation intercepted was about 1.2 times higher in the narrow rows and averaged 70.6% and 59% in the narrow rows and wide rows, respectively.

Average seasonal albedo was 0.20 for the narrow rows and 0.18 for the wide rows. Although albedo was higher in the narrow rows, reflectance in the 400 to 500nm and 600 to 650nm wavebands was about the same for both plots. Since LAI and climatic conditions were similar for both plots throughout the growing season, these differences seem to have arisen as a result of the differences in cropping pattern and consequently differences in plant cover.

CHAPTER II

MICROCLIMATE OF NARROW AND WIDE ROW SORGHUM

Microclimate may be considered, essentially, as the prevailing distribution, near the ground, of various quantities (e.g., temperature, water vapor, air velocity, radiation and carbon dioxide). A mixture of these components operate on and influence the growth and development of crops. For example, photosynthesis in its simplest aspects, is a direct function of sunlight and carbon dioxide concentration; and it is affected, to varying extents, by air temperature, wind speed and moisture availability. The flux of water vapor and heat from the leaves to the air may also be expressed as functions of resistance to diffusion between the leaf and the air (boundary layer resistance, r_a). Similarly, CO_2 diffusion from the air into the leaf may be expressed as a function of r_a and also, resistance to diffusion within the leaf tissue and the stomates (mesophyll resistance, r_m; and stomatal resistance, r_s respectively).

The basic cause of variations in microclimate is the uniqueness that each surface (under the same bulk atmospheric conditions) displays in re-distributing energy received from the sun. In this chapter, attention will be concentrated on (1) the differences in microclimate between narrow and wide row sorghum and (2) advection (horizontal transfer of energy into the cropped area). The following subjects will be examined:

1. temperature and vapor pressure regimes within and above narrow- and wide-row sorghum,
2. temperature, vapor pressure, leaf water potential (L_Ψ), and r_s along the direction of the wind--as means of detecting advection, and

3. wind speed profiles within and above the crop.

Extensive studies of temperature and water vapor within crops have been reported in the literature. Penman and Long (1960) found horizontal variations in temperature over distances of 8 meters (from the edge of the field) at various levels within a wheat crop; and they reported difficulties with measurements at the top of the crop. Hand (1964), in an evaporimeter and psychrometer study of advection over lucerne in Sudan, reported that edge effects can cause inhomogeneity in temperature, vapor pressure and, hence, affect evaporation rates up to 60 meters from the edge of the plot into the cropped area. Waterhouse (1955), in an environmental study of a grass crop, found that during the day, a warm air layer was sandwiched between an upper and lower layers of cooler air. Similar observations were made by Takechi and Matsumoto (1963) who reported that denser plantings of citrus trees resulted in warmer spots developing within the crown of each tree during the day.

A diurnal trend in temperature profiles within crops has been reported by many research workers (Brown (1964) on corn; Goltz and Pruitt (1970) on turf grass; Hanks, et al. (1973) on sorghum). Brown (1964) found the 150 cm level to be the general location of highest temperature during the daytime hours. This height was also the general level at which the largest difference between air temperature and the temperature of the sunlit corn leaves existed when crop height was about 200 cm.

Millar (1964) and Pruitt and McMillan (1962) reported on the effects of advection upon the evapotranspiration and relative turigidity at varying downwind distances on Ladino clover and rye-grass, respectively. They found that under advective conditions, evapotranspiration decreased and relative turigidity increased with increasing downwind distance for the first 14 meters and that both variables changed as a function of the downwind distance. Similar effects of advection have also been presented by Tanner (1957), van Bavel et al. (1963), Rider et al. (1963) and Webb (1965) who also reported on downwind changes of humidity as air moved from a dry area into a vegetative or wet area.

METHODS AND PROCEDURE

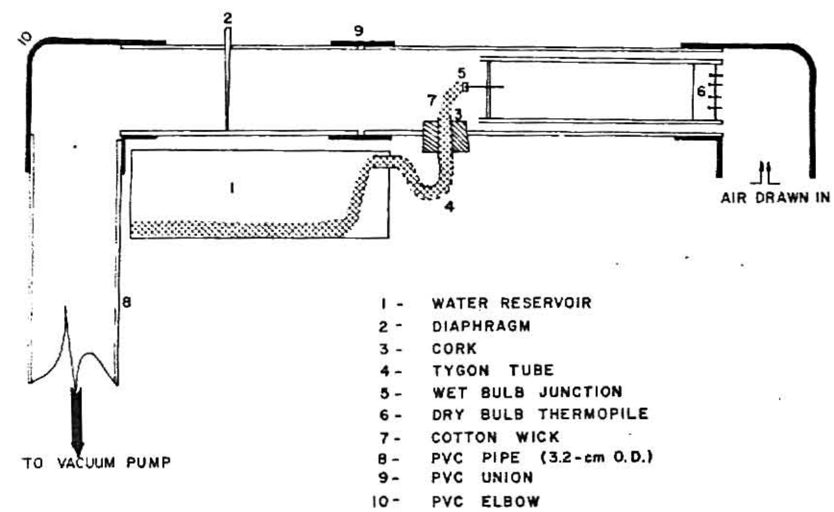
Earlier report of large scale advection has been made for this location (Chin Choy and Kanemasu, 1974) towards latter part of sorghum development with prevailing southerly winds. Five masts similar to those used by Brown (1964) were, therefore, erected along the N-S direction on July 11 (Fig. 1). Each mast measured air temperature and vapor pressure at 6 heights within and above the crop canopy. The psychrometer unit consisted of dry bulb and wet bulb thermopiles (to increase signal output). Thermocouples were potted in .5-cm diameter acrylic rods giving a time constant of between 20 and 24 seconds. The sensors were housed within two concentric polyvinyl pipes; the units and water reservoir were then wrapped with a sheet of aluminized mylar to reflect and emit radiation. Fig. 2 shows a line drawing of an arm of one of the masts.

Air flow in each arm (adjusted to 3m sec^{-1}) was maintained with vacuum cleaners (Kenmore model No. 208.61120). These arms were at heights of 10, 40, 70, 110, 160, and 210 cm above the ground until August 6 when the masts were raised so that the fourth level corresponded with the height of the crops. The new heights were then 29, 59, 89, 129, 179 and 229 cm above the ground.

The cotton wicks on the wet bulbs were changed weekly; but more often when abnormal vapor pressure was observed. The ambient vapor pressure

Fig. 2

An arm of the temperature and vapor pressure profile-measuring masts



(e) was derived from the dry bulb and wet bulb temperature readings using the following equation:

$$e = e_s - \gamma (T - Tw) \qquad (2.1)$$

where e_s is the saturation vapor pressure; T is the dry bulb temperature; Tw, the wet bulb temperature and γ is the psychrometric constant.

Soil surface temperature was measured with copper-constantan thermocouples (5 connected in parallel at each location). The thermocouples were referenced to ice-point (Ref-Cel 136)[6] in the instrument shelter.

Weekly measurements of stomatal diffusion resistance (r_s) and leaf water potential (L_ψ) were made on the first collared leaf of 3 plants around each mast using stomatal diffusion porometer (as described by Kanemasu and Tanner, 1969) and pressure bomb respectively. Measurements were made twice on each day considered (1000 and about 1500 hours).

Wind Speed

Wind speed was measured (only on the wide rows) at 6 heights--16, 35, 75, 155 and 315 cm above the ground using cup anemometers manufactured by Thornthwaite Associates.[3] Wind speed was computed as shown below:

$$V = 11.49 + 2.567C - .000448C^2 + .0000002873C^3 \qquad (2.2)$$

where

C = revolutions per min and

V = speed in cm per sec.

RESULTS AND DISCUSSION

Temperature profiles from masts 4 and 5 (Fig. 1) were plotted

[6]Hy-Cal Engineering, 1205 Los Wietos Road, Santa Fe Springs, California 90670.

throughout the day for July 15 when LAI was maximum (above 5) and August 7 when LAI had declined to about 4 (Fig. 2.1 and 2.2).

Early in the morning (0910 on July 15; 0839 on August 7), temperature profiles were similar for both plots; however, by 1110 of July 15 and 1035 of August 7, soil surface temperature was 3°C and 1.5°C, respectively, higher on the wide rows than in the narrow rows. Temperature was maximum for the wide and narrow rows, respectively at 1440 and 1640 on July 15 (Fig. 2.1). In general, the air temperatures were higher in the wide rows than in the narrow rows; the largest temperature difference being about 1°C and occurring in the afternoon.

Fig. 2.1 shows a temperature inversion at 10 cm height in the narrow and wide rows before noon. The canopy temperature (air temperature in the canopy) at this time was higher than the soil surface temperature for the narrow rows. This may be explained by the almost uniform crop cover provided by overlapping leaves between the rows in the narrow row plot; as opposed to leaves-bare ground juxtapositions in the wide rows which allowed direct penetration of the sun's beam to the soil surface especially by August 7.

The region of highest temperature within the crop canopies lies between 40 and 80 cm height above the ground. This is the region where the leaves were concentrated (Fig. 2.5a) and hence functioned, more or less, like the soil as an exchange surface. This is consistent with the results of Waterhouse (1955) over a grass crop and Takechi and Matsumoto (1963) within the crown of citrus trees. The temperature difference between the crop canopies (narrow and wide rows) never seemed to exceed 2°C at any given time (Figs. 2.3b and 2.4b).

Vapor pressure was consistently higher in the narrow rows than in

Fig. 2.1

Temperature profiles on July 15

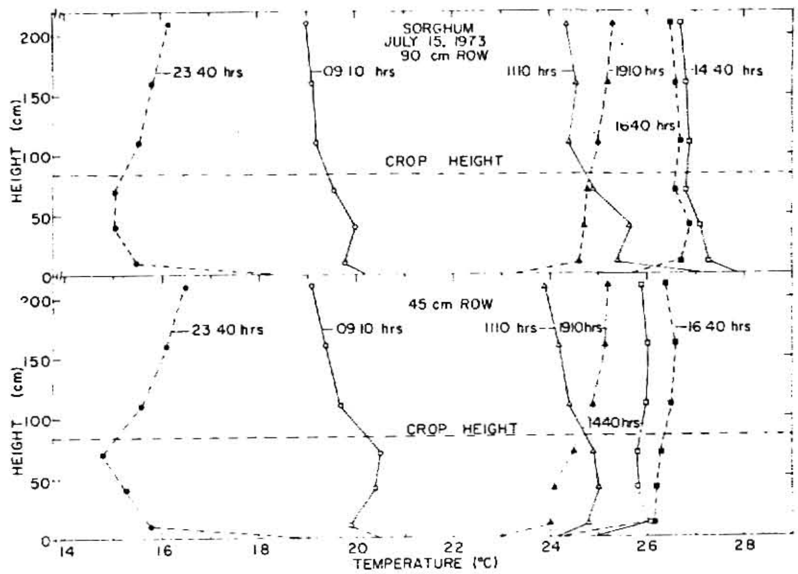


Fig. 2.2

Temperature profiles on August 7

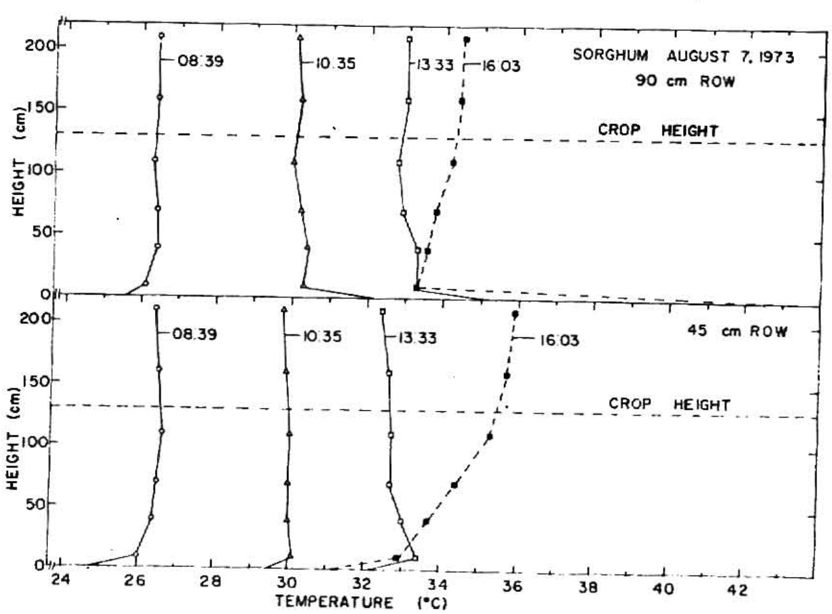


Fig. 2.3

Vapor pressure and temperature profiles in the morning and afternoon of August 7

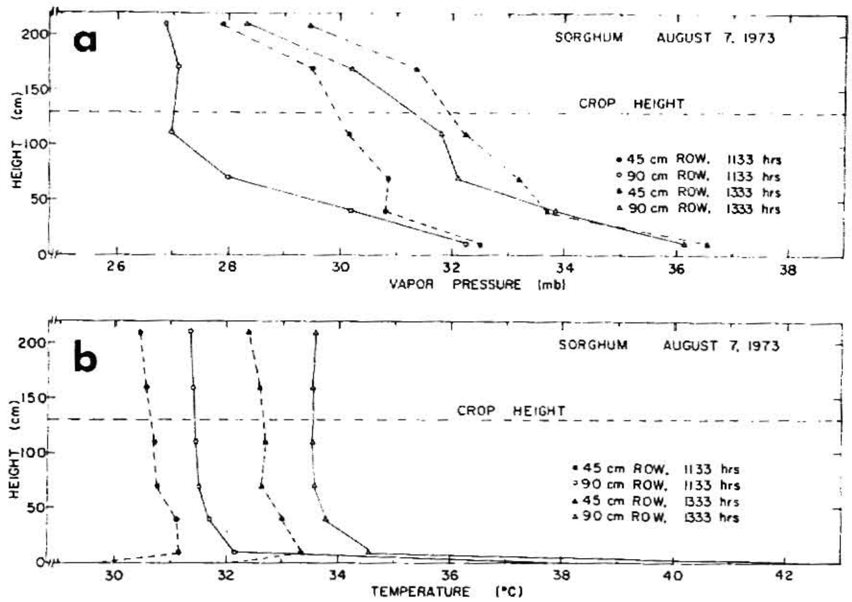
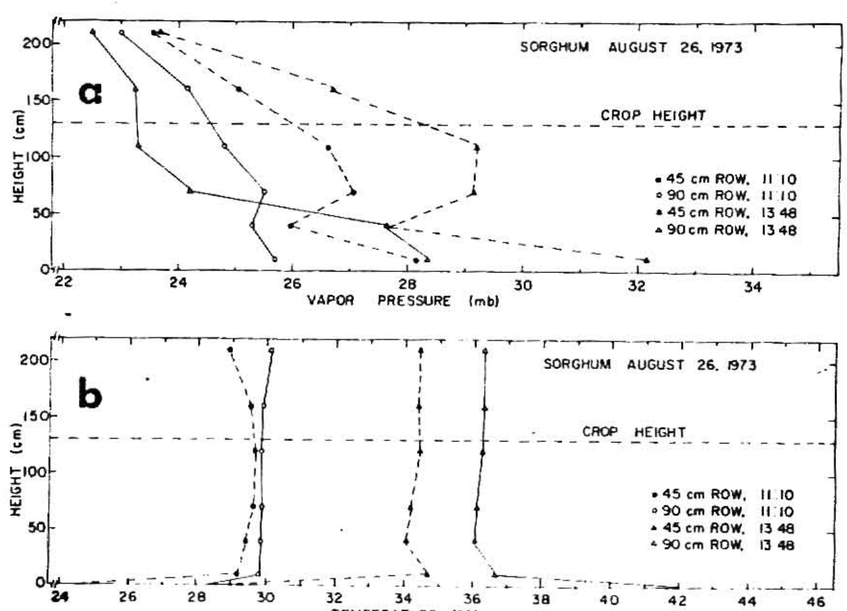


Fig. 2.4

Vapor pressure and temperature profiles in the morning and afternoon of August 26



the wide rows--showing a difference as high as 6 mb at the 80-cm height on August 26 (Fig. 2.4a). This can be as a result of one or both of the following factors:

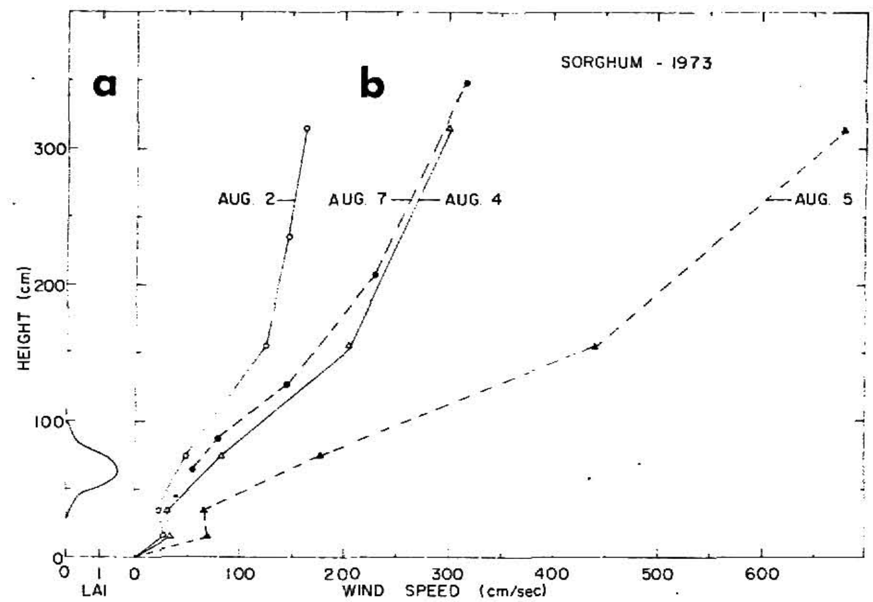
1. higher transpiration in the narrow row canopy and
2. reduced between-row air movement in the narrow row plot.

Considering the similarity in LAI, radiation load, and soil water supply between the two canopies, a higher transpiration (discussed in Chapter III) in the narrow rows may aid in explaining some but not all the difference in vapor pressure--especially since there is a feedback between high vapor pressure and transpiration. Reduction in between-row air movement in the narrow rows may also be responsible for the higher vapor pressure.

The distorted-Z-shape of vapor pressure profiles obtained for August 7 and 26 would appear rather unusual (Fig. 2.4). Similar profiles were, however, obtained for the 0900-1200 time period by Rijks (1961) over cotton in Wad Medani, Sudan and supported by the data of Hanks, et al. (1972) within and above sorghum for August 16, 17, 18, 22, 28 and 30. This is assumed to result from (1) higher moisture loss through transpiration than soil evaporation, and (2) reduced mixing of air layers around the leaves and close to the soil surface in the narrow rows. The wind speed profile at 1500 hours, plotted for several days in the latter part of the growing season, supports (2). The profiles (Fig. 2.5B) show that wind speed was higher at 15 cm height than at 35 cm above the ground. This implies that a tunnel of air goes below the region of high leaf concentration. This is similar to the "blowthrough" phenomenon in the forest canopies reported by Lemon (1969). The lower vapor pressure at about 20-40 cm height implies that water vapor moves into this region from the soil

Fig. 2.5

LAI by strata and wind speed profiles during the season



below and the leaves above; therefore, the wind tunnel constitutes the sink for the fluxes of water vapor.

Advection

Advection generally refers to a situation where energy is transferred from remote or adjacent areas into fields or plots. It is classified into large scale, within-row, or border advection, depending on source of energy. Large scale advection is characterized by a temperature inversion above the crop canopy while border advection is, generally, distinguished by a horizontal change in temperature and vapor pressure from the edge to a relatively short distance into the field (Hand, 1964).

Evidences for large scale and border advection fall into one or more of the following categories:

1. ratio of $^{LE}/_{Rn}$ greater than 1,
2. air to surface transfer of sensible heat reflected in the negative values of H (temperature inversion),
3. decreased temperature, near the surface, along the direction of the wind, and
4. increased humidity and plant turgidity downwind.

In addition to the effects mentioned above, within-row advection is characterized by the transportation of warm air between rows culminating in high soil temperature.

The first two effects (as listed above)--dealing with ratio of $^{LE}/_{Rn}$ and the negative values of H, will be treated in Chapter III under energy balance. Temperature profiles from masts 1 to 4 in downwind direction are shown in Figs. 2.6 to 2.9. Graphs of earlier dates were not plotted since these days did not show any obvious temperature patterns (wind

Fig. 2.6

Temperature profiles from masts 1 to 4 at about 1500 hours on August 11

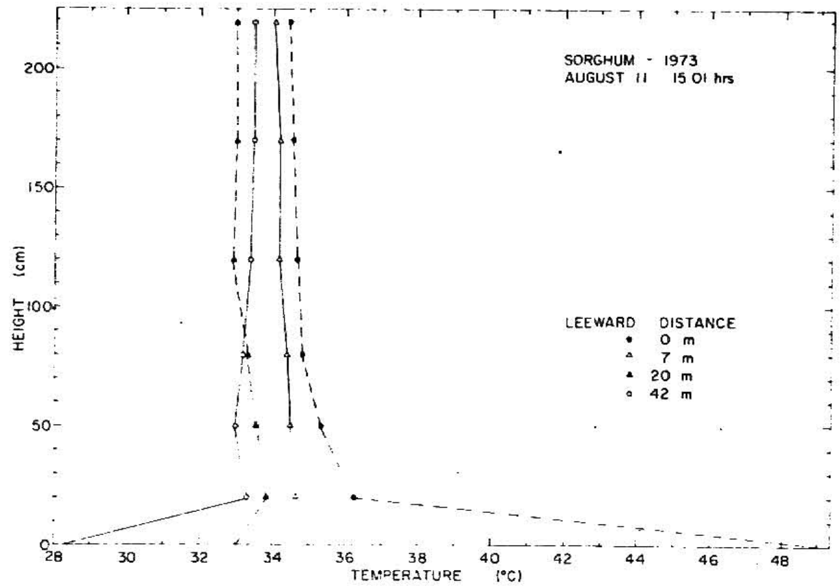


Fig. 2.7

Temperature profiles from masts 1 to 4 at about 1500 hours on August 16

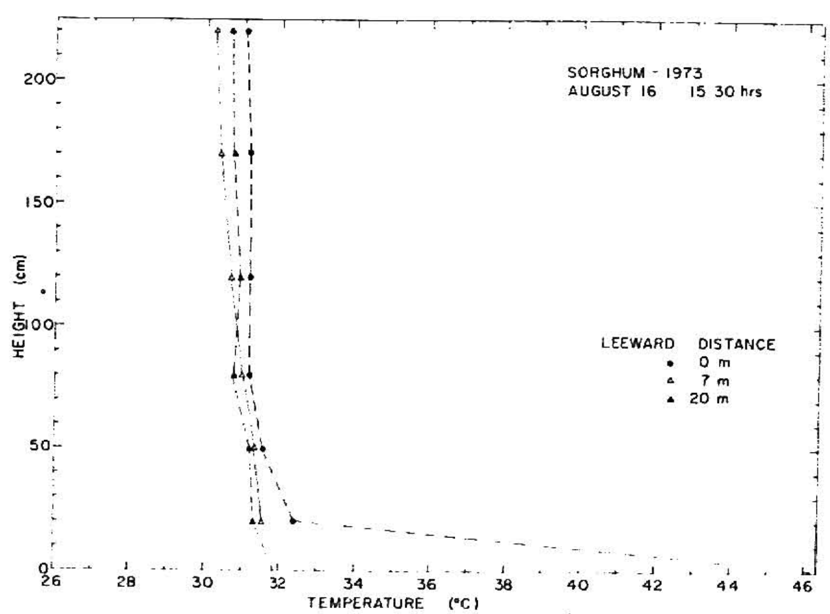


Fig. 2.8

Temperature profiles from masts 1 to 4 at about 1500 hours on August 25

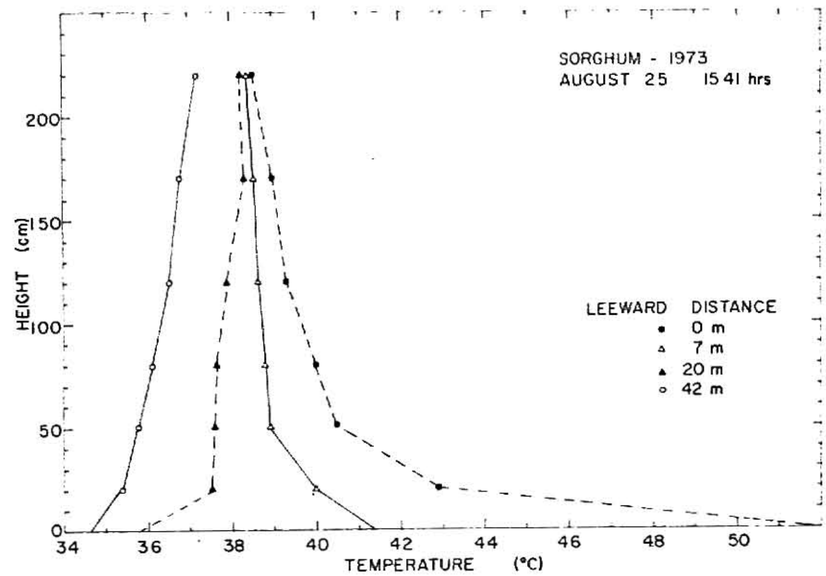
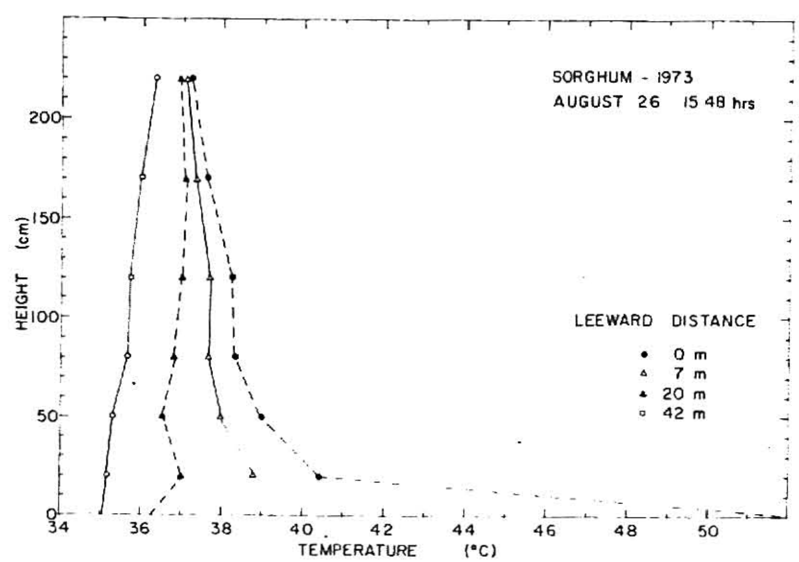


Fig. 2.9

Temperature profiles from masts 1 to 4 at about 1500 hours on August 26



direction was not parallel to the masts). Masts 1 to 4 were spaced, in order, at 0, 7, 20 and 42 meters from the southern edge of the plot.

In general, temperature, from the soil surface to about 90 cm height, was declining with increased distance in the leeward direction (downwind). Soil surface temperature was much higher than air temperature around masts 1 and 2. The maximum difference between soil surface and air temperature was 14°C (Mast 1, Fig. 2.6). Hanks, et al. (1972) reported a difference of about 20°C between soil surface and plant surface temperature under advective conditions in the Central Great Plains.

August 25 and 26 profiles (Figs. 2.8 and 2.9) showed distinct temperature inversions at about 50-cm height for masts 3 (20m) and 4 (42m). This is indicative of warmer air layer above the crop than in the canopy. The temperature measurements from mast 4 (Fig. 1) were much lower than those from masts 1, 2 or 3. This is because the air was not in equilibrium with the surface until about 42m from the edge of the plot; the temperature profiles of masts 4 and 5 were quite similar.

Figs. 2.10 and 2.11 show the vapor pressure profiles for August 11 and 16 at about 1500 hours. Profile 3 (August 11) and profile 4 (August 16) are omitted because of instrument malfunction. Vapor pressure at any given height increased with downwind distance. This is in agreement with the findings of Hand (1964), Goltz and Pruitt (1970) and Hanks, et al. (1972). The larger difference in vapor pressure between the first and fourth masts at the 20 cm height on August 11 (Fig. 2.10) than for the first and third masts on August 16 (Fig. 2.11) were presumably because of differences in the degree of soil wetness. The plots had received 7.5 cm of rain and irrigation water within the 4 days prior to August 11; as compared to only 1.75 cm for the same time interval before August 16.

Fig. 2.10

Vapor pressure profiles from 3 masts at about 1500 hours on August 11

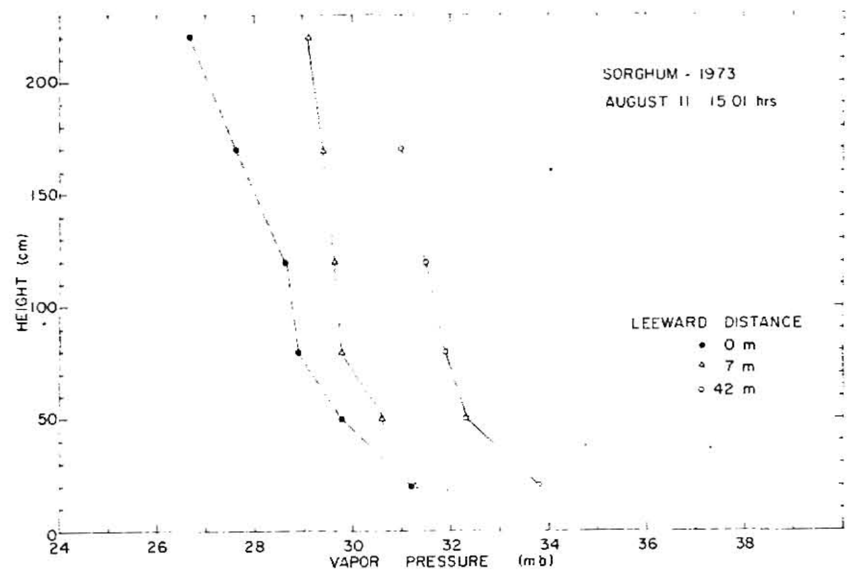
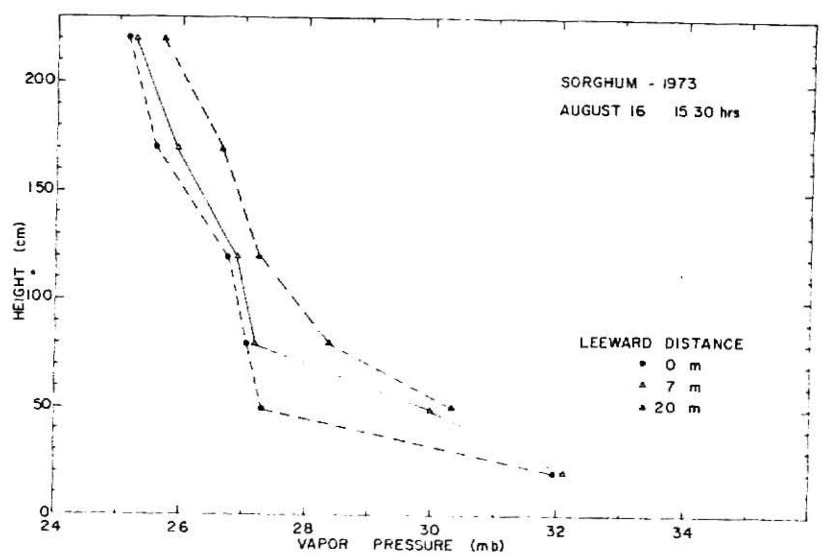


Fig. 2.11

Vapor pressure profiles from 3 masts at about 1500 hours on August 16



Stomatal resistance (r_s) and leaf water potential (L_ψ) data around the masts are presented in Tables 2.1 and 2.2 for several days during the season. The low r_s measurements (below 5 sec/cm except for July 13 and August 6) indicate sufficient moisture supply to the crops throughout the season. Stomatal resistance was highest around mast 1 (wide-row plot) and generally lowest around mast 5 (narrow-row plot) which was 92 meters away from the edge of the fallow. The mean r_s at the masts were, however, not significantly different at 5% probability. The daily leaf water potential data showed a general increase (less negative) with increasing distance along the path of the wind (downwind); therefore, an increasing relative turgidity downwind is indicated (Hanks, et al. 1972). Leaf water potential at mast 5 was not significantly different from L_ψ around mast 3 or 4 but L_ψ at masts 3, 4 and 5 are significantly lower than L_ψ at mast 1 (5% probability). Lower L_ψ and greater r_s around masts 1 and 2 is assumed to reflect the plant's active effort to restrict excessive water loss (Szeicz, van Bavel and Takami, 1973).

SUMMARY

Temperature, vapor pressure and wind speed measurements were made within and above narrow- and wide-row sorghum. Leaf water potential and stomatal resistance measurements were also made on the first collared leaf of plants around each of 5 masts erected along the prevailing wind direction.

Temperature and stomatal resistance decreased with increasing distance in the leeward direction. Vapor pressure and leaf water potential, however, increased with increasing distance from the edge of the field. Temperature inversions above the crop (warmer air layer above the crop)

Table 2.1

Stomatal diffusion resistance (sec/cm) of sorghum leaves at the 5 masts and at the lysimeters taken at 1300 to 1500 hours

MASTS

Day	Time	1	2	3	4	5
July 11.	1330	3.62	2.53	4.75	2.88	1.9
13	1500	4.06	5.87	4.09	3.55	3.62
Aug. 6	1500	1.40	1.11	1.14	2.34	1.33
17	1530	3.50	1.33	1.41	2.18	1.10
21	1500	1.8	1.28	1.33	0.97	1.65
22	1530	1.17	0.73	0.42	0.57	0.68
Average		2.59	2.14	2.19	2.08	1.71

Std. Deviation = 1.47

L.S.D. 0.05 = 1.75

LYSIMETERS

Day	Wide Row	Narrow Row
July 2	2.33	2.23
10	3.82	1.35
11	1.99	1.49
18	2.94	2.03
27	3.59	3.04
31	3.61	1.12
Aug. 3	0.76	0.79
6	6.99	5.71
16	1.24	0.82
27	1.14	1.22
Average	2.84	1.98

Table 2.2

Leaf water potential (bars) at the 5 masts taken between 1400 and 1500 hours (bars)

	MASTS				
Date	1	2	3	4	5
July 11	-13.7	-12.2	-12	-13.4	-11.3
13	-15.4	-14.4	-14.4	-13.5	-11.1
Aug. 7	-12.3	-12.3	-10.5	-10.0	-11.2
17	-13.2	-13.0	- 9.2	-10.8	-10.4
21	-15.5	-14.2	-12.3	-12.3	-11.9
22	-15.4	-13.8	-11.9	-11.8	-10.5
Average	-14.25	-13.30	-11.72	-11.97	-11.07

Std. Deviation = 1.28

L.S.D. 0.05 = 1.52

confirm an earlier report of large scale advection towards the latter stages of crop development at this location (Chin Choy and Kanemasu, 1974). A tunnel of air moving below the level of maximum leaf concentration (35-80 cm) constitutes the sink for water vapor moving in from transpiring leaves and the soil surface.

CHAPTER III

ENERGY BALANCE OF NARROW AND WIDE ROW SORGHUM

The energy balance of a crop for steady state conditions is generally written as:

$$Rn = G + LE + H + PR \tag{3.1}$$

where Rn is net radiation; LE is energy consumed in evapotranspiration; G is the soil heat flux and H is the sensible heat flux. PR represents energy stored or released by the system (includes photosynthesis and respiration). This quantity is often negligible when compared to the other components of the energy balance equation and is, therefore, often omitted in the equation.

The partitioning of Rn into its various components is of agronomic significance. Higher water use efficiency would result if methods could be found to decrease the energy used in evaporating water and, alternately, increase the energy used in photosynthesis.

Brown (1964) reported that for corn crop, 46% of the net radiation was used for transpiration, 13% for soil evaporation, 32% for sensible heat flux and 6% for soil heat flux. Jensen and Haise (1963) also reported that about 55% of Rn above corn crops after tasseling is used for evapotranspiration. Fritschen (1966) found, by means of the energy balance method, that LE/(Rn-G) averaged 1.26 for sorghum and 1.22 for small grains in Southwestern U.S.

Albertin and Peters (1961) found that plant population and row width affected the relative amounts of energy absorbed by corn plants and by the soil. They observed that 20 inch (50 cm) row plants absorbed 3.1 times more energy than 40 inch (100 cm) row plants; and the soil of the 40 inch rows absorbed 1.4 more energy than the soil of the 20 inch rows. Yao and Shaw (1964), measuring the net radiation above and within corn crops of various row spacing and plant densities, found that closer row spacing with similar populations was more effective in extracting net radiation before it reached the ground.

Similar studies on energy balance comparisons of wide and narrow rows was also reported by Chin Choy and Kanemasu (1974). They found LE to be 10% higher in 92 cm rows than in 46 cm rows and attributed the higher LE in the wide rows to high within-row and large-scale advection. It was not possible to separate the effect of higher plant population (in the narrow rows) on the difference in LE for the narrow and wide rows. This report, therefore, aims at:

1. comparing energy balance components for narrow and wide row sorghum with equal plant density,
2. comparing LE measured using lysimeters with LE estimated by combination and resistance methods,
3. partitioning LE into evaporation and transpiration, and comparing evaporative flux obtained by the energy balance and soil can methods.

METHODS AND PROCEDURE

Net Radiation

Net radiation above and below the crop canopies were taken as described in Chapter I.

Soil Heat Flux

Soil heat flux was computed using data from heat flow discs buried at 5-cm depth (3 flux plates in each plot) together with heat storage in the top 5 cm

$$G_o = G_z + C(^{\Delta T}/_{\Delta t}) \qquad (3.2)$$

where G_o is the soil heat flux at the surface; C is heat capacity of the soil in the top 5 cm; Δt is the unit change in time; G_z is the measured soil heat flux at 5 cm depth. Soil moisture samples from the top 5 cm were taken twice every week for computing C.

Evapotranspiration

LE was measured with two lysimeters (one in each plot). The lysimeters were located in the center of the plots. The voltage from the lysimeter load cells was monitored every 20 minutes. The voltage difference between consecutive readings was multiplied by appropriate calibration factor to compute the evapotranspiration rate. Estimates of LE were also made from the vapor gradients obtained from the masts and the wind speed profiles.

Theoretical Considerations

LE consists of the conversion to vapor and mixing with the atmosphere of the liquid water at the earth-atmosphere boundary (Tanner, 1967). Conventional methods of measuring LE may be divided into two main classes:

1. hydrological method (e.g., lysimeter)
2. micrometeorological methods (e.g., combination, energy balance, aerodynamic and resistance methods).

While this paper does not intend to discuss the merits and demerits of each of these methods, it will attempt to compare LE obtained by combination, resistance, and lysimetric methods.

The vertical flux of sensible (H) and latent heat (LE) may be expressed using Fick's diffusion equations:

$$H = C_p \rho K_H \left(\frac{\Delta T}{\Delta Z}\right) \qquad (3.3)$$

$$LE = \frac{\lambda \rho \epsilon}{P} K_W \left(\frac{\Delta e}{\Delta z}\right) \qquad (3.4)$$

where Cp is the specific heat of air at constant pressure; ρ is the density of air; K_H and K_W are the exchange coefficients of heat and water vapor respectively; T, the air temperature; Z, the height above the ground; λ, the latent heat of vaporization for water; P, the atmospheric pressure and ϵ, a constant. The exchange coefficients, K_H and K_W are assumed equal (King, Tanner and Suomi, 1956; Graham and King, 1961; Wright and Lemon, 1962). It is solved for from equations (3.1), (3.2) and (3.3) as

$$K = \frac{Rn - G}{\rho\left[C_p \frac{\Delta T}{\Delta Z} + \frac{\lambda \epsilon}{P} \frac{\Delta e}{\Delta Z}\right]} \qquad (3.5)$$

The constants (P, C_p, λ, ϵ) are known; the other parameters can be measured and K substituted into equation (3.3) to obtain LE (combination).

Potential evapotranspiration (Penman, 1963) and LE (resistance method) were estimated as shown below:

$$LE\ (\text{potential}) = \frac{\frac{S}{\gamma}(Rn - G) + .0107(1 + .005376V)\ (e^* - e)}{\frac{S}{\gamma} + 1} \qquad (3.6)$$

$$LE = (Rn - G) - [\rho C_p\ (Tc - Ta)/ra] \qquad (3.7)$$

where

$$r_a = \frac{\ln\left(\frac{Z + D}{Zo}\right)^2}{k^2 V} + \Phi^2 \qquad (3.8)$$

Tc, crop temperature

Ta, air temperature at 2 meter height

S, slope of the vapor pressure curve $(^{\Delta e}/_{\Delta z})$

γ, psychrometric constant

V, wind speed at a height of 2m in km/day

$D = d + Z_o$ = displacement parameter due to the presence of vegetation

Φ = integral diabatic influence function = $\int_{Z_o}^{Z+D} \varphi \, Z^{-1} \, dz$

when $\varphi = 1$, $\Phi = 0$

d, zero plane displacement

Z_o, roughness parameter.

For diabatic conditions (as obtains here), a correction factor was incorporated into equation (3.8) to account for the effect of thermal buoyance. Thus, Richardson's number was obtained as

$$Ri = \frac{g}{\overline{T}} \frac{(T_2 - T_1)\,(Z_2 - Z_1)}{(V_2 - V_1)^2} \tag{3.9}$$

where g is a gravitational constant; $\overline{T}$ is the average temperature between Z_2 and Z_1. R_i was used to evaluate the correction factor

$$\varphi = (1 - 18Ri)^{-\frac{1}{4}} \tag{3.10}$$

Crop Temperature

Tc was measured with Barnes infrared thermometer (Type IT-3).[7] The optical sensing head of the thermometer was enclosed in a large, white, styrofoam cup to minimize solar heating. The amplifier unit was enclosed in a white wooden box. The sensing head was mounted at a height of 2.5m above

[7]Barnes Engineering Co., 30 Commerce Road, Stanford, Conn. 06902.

the soil and traversed 3 rows in the wide row plot (speed, 2 $cm.sec^{-1}$). The emmisivity of the crop was assumed to be unity.

Sensible Heat Flux

Sensible heat flux (H) was computed as a residual of the energy balance equation (3.1); PR was assumed insignificant and H was computed as:

$$H = Rn - (G + LE) \tag{3.11}$$

Evaporation from Soil Surface

Evaporation from the soil surface is:

$$E_s = Rn' - G - H_s \tag{3.12}$$

where Rn' is the net radiation below the canopy and H_s is the sensible heat flux from the soil. When H_s is zero, maximum evaporation is computed as

$$E_s = Rn' - G \tag{3.13}$$

Equation (3.13) was used in computing evaporation, E_s. The assumption ($H_s = 0$) is not valid considering the temperature gradients (from the soil surface through the crop canopies) obtained in Chapter II. Figs. 2.2 to 2.4 show H_s (wide row) greater than H_s (narrow row). This model was, however, used by Brun, Kanemasu and Powers (1972) for the same soil and similar climatic conditions. Towards the end of the growing season, 12 soil cans (6 on each plot) were also used to estimate E_s. Each can had a surface area of 248 cm^2 and was buried to a depth of 15 cm in the soil. These cans were weighed twice a day (at about 0900 and 1700 hours). Energy consumed in evaporation during the day was

$$E_s \text{ (soil cans)} = \frac{\lambda(W_2 - W_1)}{A} \tag{3.14}$$

where W_2 and W_1 are weights of the soil can in the morning and afternoon respectively and A is the area of the soil can.

Transpiration

Since LE is a sum of water losses through evaporation and transpiration, energy used us in transpiration (E_T) was computed as the difference between LE and E_s:

$$E_T = LE\ (\text{lysimeter}) - E_s\ (\text{energy balance}) \qquad (3.15)$$

RESULTS AND DISCUSSION

Fig. 3.1 shows the graphs of LE for the narrow and wide rows, and LE (potential) throughout the season. In the period between June 10 and July 5, the soil surface was frequently dry. Precipitation was limited and the plants were not fully developed. There was, therefore, a large difference between LE and potential LE. Later in the season, however, the sorghum functioned much like a wick (as described by Chin Choy and Kanemasu, 1974). Although the soil surface was not completely wet during this period, the plants' roots were effective in taking water out of the soil profile. Evapotranspiration was slightly higher in the wide rows than in the narrow rows early in the season (till about June 20). During the latter part of the season, LE was similar for both narrow and wide rows. Fig. 3.2 shows the relationship of LE/LE (potential) with LAI. Maximum LE occurred at LAI of 3.5 and above ($^{LE}/_{LE}$ (potential) was equal to 1 at LAI = 3.5).

The parameters of the energy balance for 9 clear days after heading stage, when leaf area index for both plots was over 3.5, are shown in Table 3.1. Net radiation on the two plots showed no significant difference even at 1% level.

Fig. 3.1

LE and potential LE throughout the season

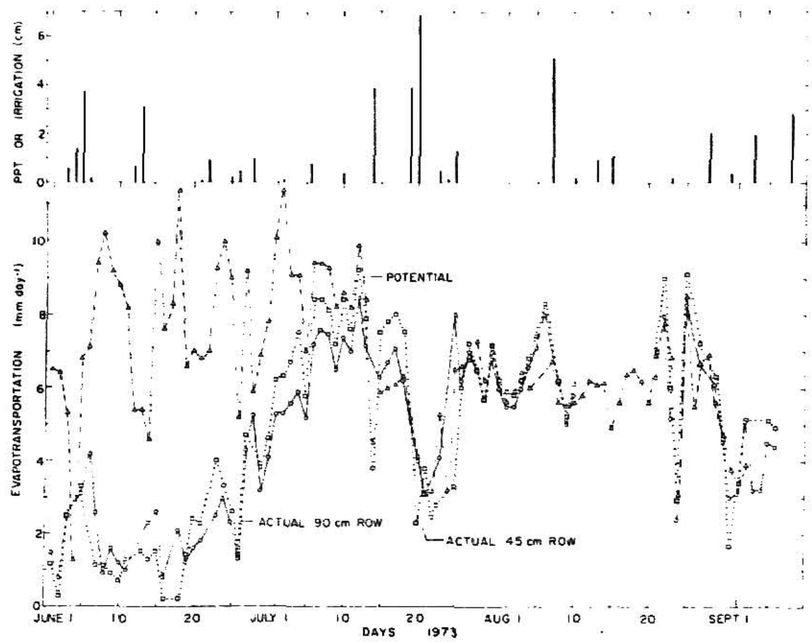


Fig. 3.2

Relationship of LE/LE (potential) with LAI

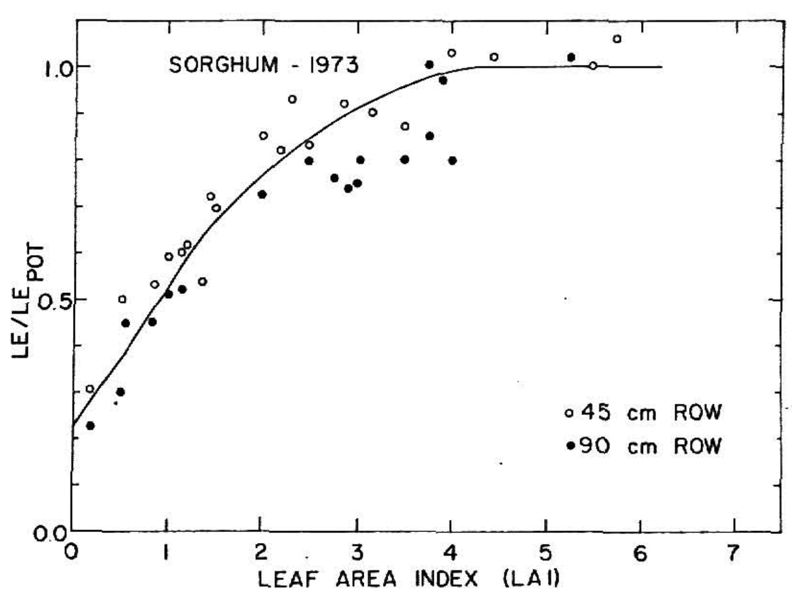


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Table 3.1. Total energy balance terms fro 0900-1800 hours (Unit - cal/cm^2/day).

Day	Row-width cm	Rn	G	H	LE	%LE/Rn	Wind run km/day
July 12	45	429	38	-4	395	92	290
	90	429	68	-25	386	90	
July 13	45	414	34	-5	385	93	266
	90	405	115	-75	365	90	
July 25	45	419	28	156	235	56	149
	90	423	72	59	292	69	
July 26	45	423	43	50	330	78	110
	90	429	80	27	322	75	
August 10	45	421	41	54	326	77	101
	90	427	64	49	314	74	
August 16	45	426	46	48	332	78	105
	90	413	78	6	329	80	
August 20	45	387	50	15	322	75	140
	90	396	84	-28	340	88	
August 25	45	363	45	-82	400	110	276
	90	360	74	-112	398	111	
August 26	45	358	40	-46	364	101	324
	90	357	69	-102	390	109	
Average	45	399	40	9	350	88	
	90	400	80	-35	355	89	

The major proportion of energy absorbed in the canopies was dissipated as LE (Figs. 3.3 and 3.4). This proportion, LE/Rn, ranged between 56 to 110 percent for the narrow rows and 69 to 111 percent for the wide rows (Table 3.1). The average ratio of LE/Rn was .88 for the narrow rows and .89 for the wide rows. The 1% difference in LE between the narrow and wide rows obtained here represents an average of about 5 langleys per day higher energy consumed by the wide rows in evaporating water off the soil and plants. This is much lower than the 10% difference obtained by Chin Choy and Kanemasu (1974) for the same location in the previous year. It must be noted, however, that their narrow-row plot had about twice the plant density of the wide row plot - as opposed to the equal plant density plots being investigated in this experiment. In addition, the plots in this experiment were more frequently irrigated than those reported by Chin Choy and Kanemasu.

Percent LE/Rn of over 100 as obtained for the wide-row plots on August 25 and 26 implies more energy was used in LE than can be accounted for by Rn. In addition, temperature inversion at the 50 cm height was also reported for both days in Chapter II (Figs. 2.8 and 2.9). These, coupled with the negative values of H as from August 20, confirm the occurrence of large-scale advection in the plots towards the later part of the growing season.

Hanks et al. (1972) estimated advection at 39 ly/day (0.16 cm/day) for 8 days (August 16-24) over irrigated sorghum in the Central Great Plains (Akron, Colorado).

We estimated advection as high as 82 and 112 ly/day for the narrow and wide row canopy, respectively (Table 3.1).

G was consistently higher in the wide rows while the narrow row plot lost more energy through H (for July 12 to August 16) and absorbed less energy in H towards the latter part of the growing season. The average of the parameters in Table 3.1 further emphasizes the difference in energy partitioned to G and H for both plots. The magnitude of G for the wide rows was twice that for the narrow rows. And while the overall average of H for the narrow rows indicate a loss of energy to the environment, that for the wide rows shows a net absorption of energy from the air around the crop.

An attempt to simulate the evaporative loss of water from the field with soil cans was abortive until the late part of the growing season when the water in the cans was re-adjusted to match the soil water content in the field; and the cans positioned in more representative sites within the crop canopies (Table 3.2). Thus E_s (E.B) obtained using equation (3.13) and E_s (cans) agree only for August 29. The higher evaporation from the soil cans also suggest that the metal containers increased evaporation from the soil in the cans.

Percentage E_s (E.B)/LE calculated for 6 days (Table 3.2) after heavy rains or irrigation showed variations ranging from 5 to 24 for the narrow rows and 9 to 26 for the wide rows. Tanner, et al. (1960), using net radiation measurements over corn estimated the percent LE going into

Table 3.1

Total energy balance terms for 0900-1800 hours
(Unit - cal/cm^2/day)

Day	Row-width cm	Rn	G	H	LE	% LE/Rn	E_a	Wind Run km/day
July 12	45	429	38	9	395	92	5	290
	90	429	68	2	386	90	25	
July 13	45	414	34	-4	385	93	5	266
	90	405	115	-52	365	90	75	
July 25	45	419	28	155	235	56	-	149
	90	423	72	65	292	69	-	
July 26	45	423	43	50	330	78	-	110
	90	429	80	34	322	75	-	
August 10	45	421	41	54	326	77	-	101
	90	427	64	51	314	74	-	
August 16	45	426	46	42	332	78	-	105
	90	413	78	4	329	80	-	
August 20	45	387	50	34	322	75	8	140
	90	396	84	-3	340	88	28	
August 25	45	363	45	-96	400	110	82	276
	90	360	74	-110	398	111	112	
August 26	45	358	40	-46	364	101	46	324
	90	357	69	-90	390	109	102	
Average	45	399	40	9	350	88		
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Halstead and Covey (1957) and Hanks, et al. (1972) estimated energy derived from advection (Ea) as the difference between LE and (Rn - G).

$$Ea = LE\ (\text{lysimeter}) - (Rn - G)$$

Advective energy, so estimated, for 8 days (August 16-24) over irrigated sorghum in the Central Great Plains (Akron, Colorado) was 39 ly/day

Fig. 3.3

Diurnal trends in energy balance terms for July 26

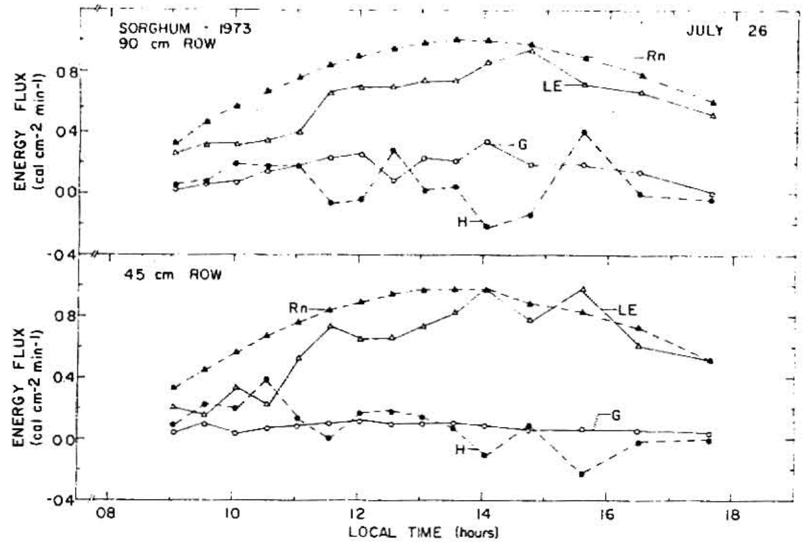
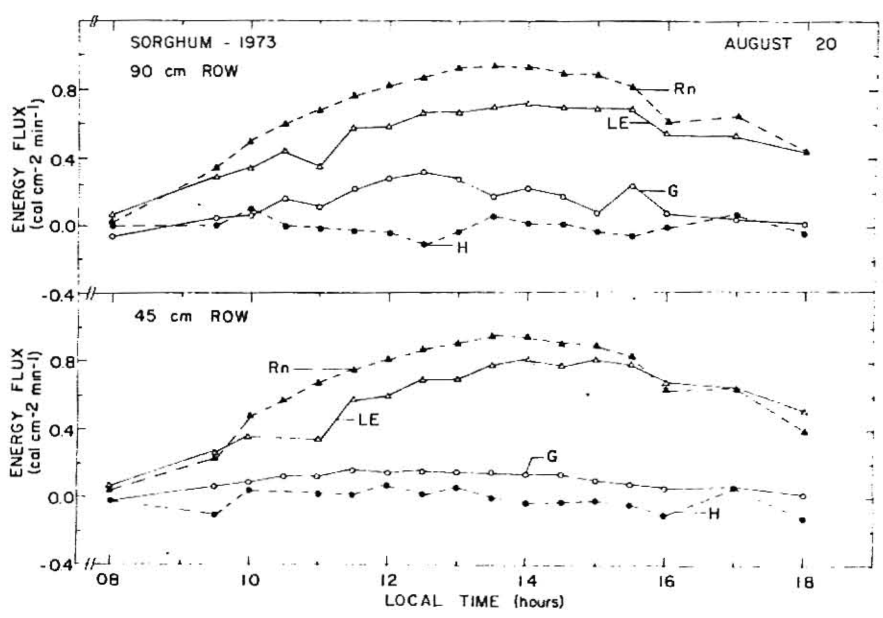


Fig. 3.4

Diurnal trends in energy balance terms for August 20



(0.16 cm/day). A similar computation was made for the 9 days considered here and Ea varied from 0-52 ly/day in the narrow rows and 0-112 ly/day in the wide rows (Table 3.1). The magnitude of Ea depended on the daily wind speed, wind direction and moisture supply in the soil. Thus, no advective energy was obtained for days with wind speed less than 140 km/day. Wind speed of over 250 km/day was measured for July 12, 13; August 25 and 26.

G was consistently higher in the wide rows while the narrow row plot lost more energy through H (for July 12 to August 16) and absorbed less energy in H towards the latter part of the growing season. The average of the parameters in Table 3.1 further emphasizes the difference in energy partitioned to G and H for both plots. The magnitude of G for the wide rows was twice that for the narrow rows. And while the overall average of H for the narrow rows indicate a loss of energy to the environment, that for the wide rows shows a net absorption of energy from the air around the crop.

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Table 3.2

Partition of LE into transpiration (E_T) and evaporation (E_s)
unit - cal/cm^2/day

Day	Row Width cm	Rn	LE	E_s(E.B)	E_s(Cans)	E_T*	% E_s(E.B.)/LE
July 12	45	429	395	28		367	7
	90	429	386	85		301	22
July 13	45	414	385	26		359	7
	90	405	365	55		310	15
July 26	45	423	330	18	-	312	5
	90	429	322	29	-	293	9
August 10	45	421	326	25	68	301	8
	90	427	314	30	73	284	10
August 16	45	428	338	28	58	310	8
	90	414	335	31	64	301	9
August 29	45	354	315	75	76	240	24
	90	352	317	84	88	233	26

*E_T calculated as LE - E_s(E.B).

evaporation to be between 25 and 50. Yao and Shaw (1964), also working with corn estimated this to be 17% when the crop is mature. Their value compares well with those obtained for August 29 when the sorghum crop was mature (LAI = 3.2). Earlier in the season, however, E_s found in this experiment was comparatively lower. This is attributed to heavier crop cover on both plots.

On July 26 when the percent E_s/LE was lowest (5% in the narrow rows and 9% in the wide rows), LAI was over 5 (Table 3.2). These values increased progressively on subsequent days as plant cover decreased. In general, the wide rows used more energy in evaporating water from the soil surface and less through transpiration. For the 6 days considered, total LE was about the same for both narrow and wide rows but evaporative loss of energy (E_s) was 5% higher in the wide rows while energy used up in transpiration was higher in the wide rows by about the same percentage.

Exchange coefficient, K, computed between the heights of 100 and 150 cm above the ground, using equation (3.5), are shown in Table 3.3 and Fig. 3.5. Computation by this method is subject to many uncertainties (Hanks, et al., 1972). Some of them are:

1. measurements must be made under conditions that no horizontal transfer of water vapor or sensible heat occurs and
2. the measurements of Δe and ΔT need be accurate.

In view of the open nature of sorghum crop and considering earlier reports of advection in this site, assumption (1) may not be valid. To overcome the second uncertainty, the wicks drawing water from the reservoir to the wet bulb junctions of the masts (Fig. 2) were cut back weekly to ensure uninterrupted wicking; and Δe (100 to 150 cm) was calculated from a linear

Fig. 3.5

Exchange coefficients throughout the day

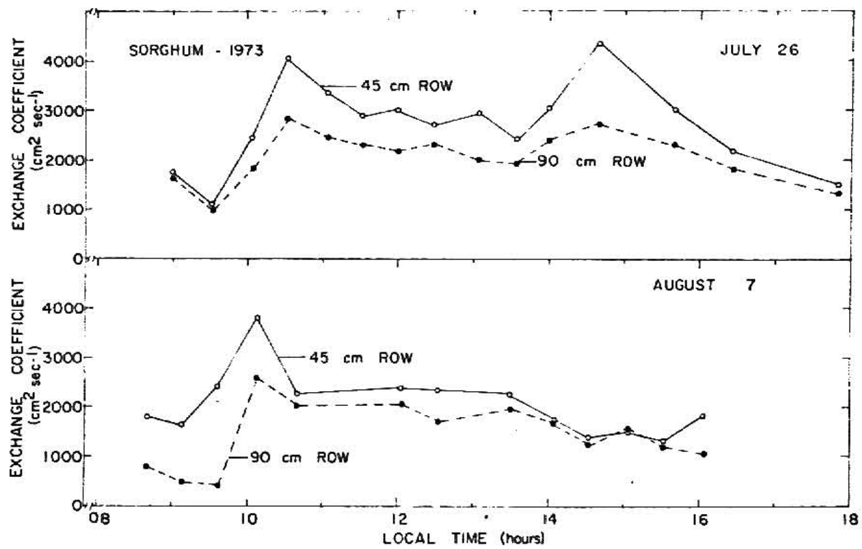


Table 3.3

Daily average of calculated exchange coefficient
(K x 1000 $cm^2.sec^{-1}$)

Day	45 cm	90 cm	Day	45 cm	90 cm
July 12	4.08	3.92	August 7	2.08	1.40
13	3.82	2.54	20	2.19	2.24
25	3.85	2.80	22	3.63	2.52
26	2.62	2.05	25	4.08	2.70
August 1	2.32	1.71	26	6.99	5.33
6	2.31	2.13	27	1.83	1.90

regression of 3 positions above the crop (Allen, Hanks, Aase, Gardner, 1974).

Generally, K was higher in the narrow rows. This may be due to a more restricted between-row wind speed in the narrow rows--resulting in increased air movement in the vertical direction (Yadin, 1950). The average K for the 12 days being 2600 cm^2/sec for the wide rows and 3320 cm^2/sec for the narrow rows. These figures compare well with the 3500 cm^2/sec reported by Begg, Bierhuizen, Lemon, Statyer and Stern (1964) over millet; 1000 cm^2/sec over wheat (Saito, 1962) and 4400 cm^2/sec over corn (Brown, 1964). Exchange coefficient computed every half hour (Table 3.4) were used in estimating LE (combination) for August 6 and 7 presented in Figs. 3.6 and 3.7.

In order to obtain LE using either combination method (equation 3.3) or resistance method (equation 3.7), miscellaneous terms (e.g., ΔT, T_c, T_a, and r_a) must be measured or estimated with varying degree of confidence. The lysimeter, if representative of the surrounds, by-pass all the uncertain measurements required in the combination and resistance methods; therefore, it provides a good reference for the other methods. The results presented in Figs. 3.6 and 3.7 gave similar LE values for the three methods in the morning (0700 to 1000 hours). In the afternoon, however, LE (combination) was almost always lower than LE obtained by the other two methods. Both combination and resistance methods tended to underestimate LE but estimates made from the resistance equation was closer to the lysimetric LE.

SUMMARY

Total energy balance parameters for 9 clear days after heading showed no significant difference in Rn above the narrow and wide rows

Fig. 3.6

Comparison of LE obtained by lysimetric, combination and resistance methods on August 6

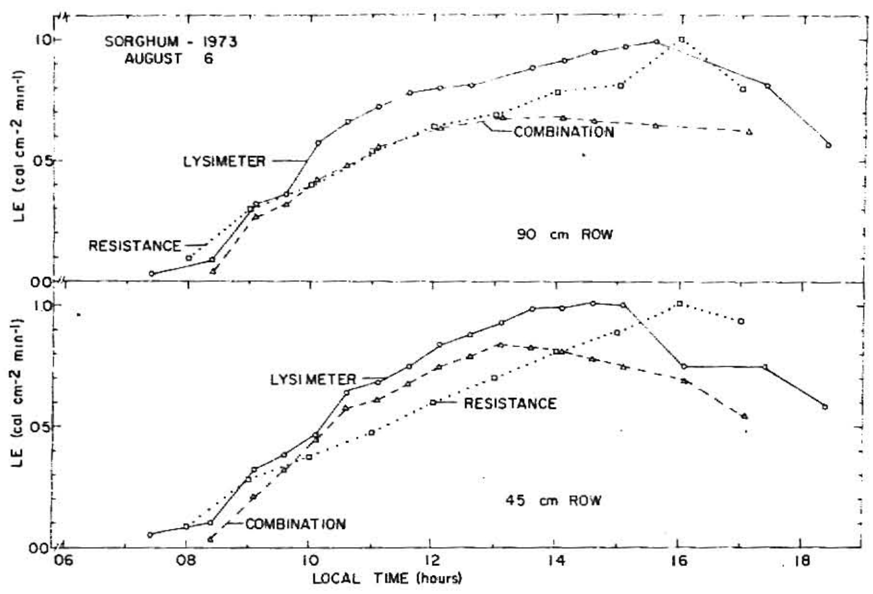


Fig. 3.7

Comparison of LE obtained by lysimetric, combination and resistance methods on August 7

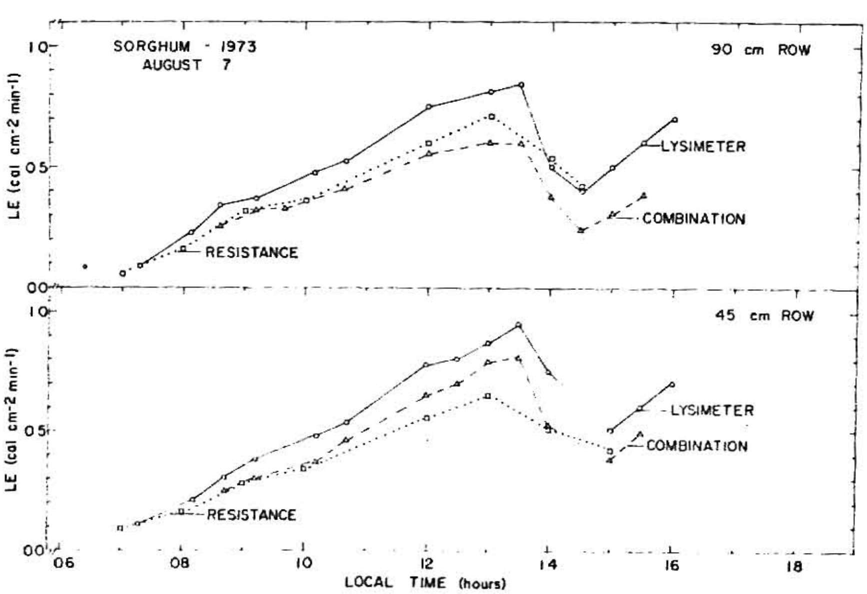


Table 3.4

Exchange coefficient and LE (combination) data for narrow and wide row sorghum
(Units: K = cm^2/sec; Rn, G, LE = $Cal/cm^2/min$)

	NARROW ROW							WIDE ROW						
Time	Rn	G	ΔT (°C)	Δe (mb)	K ($x10^3$)	LE (Combination)	LE (Lysimeter)	Rn	G	ΔT (°C)	Δe (mb)	K ($x10^3$)	LE (Combination)	LE (Lysimeter)
							August 6							
0820	.047	-.003	.11	.12	0.61	.03	.09	.049	-.001	.06	.12	0.74	.04	.09
0907	.317	.029	.05	.09	5.52	.21	.33	.328	.038	.01	.09	7.06	.27	.33
0937	.423	.033	.06	.13	5.42	.29	.39	.432	.068	.02	.13	5.83	.32	.36
1007	.534	.049	.07	.75	1.43	.45	.47	.540	.100	.03	.75	1.34	.42	.56
1037	.638	.032	.05	.76	1.80	.57	.64	.640	.153	.03	.76	1.47	.47	.66
1107	.733	.073	.06	.74	1.99	.61	.69	.736	.140	.03	.74	1.84	.57	.72
1137	.798	.089	.02	.74	2.21	.68	.75	.797	.243	.02	.74	1.73	.53	.76
1207	.865	.083	.03	.77	2.33	.75	.84	.862	.201	0	2.97	0.52	.64	.80
1237	.898	.085	.02	.78	2.41	.78	.87	.897	.260	.03	.78	1.87	.61	.71
1307	.923	.069	.01	.85	2.36	.84	.93	.914	.216	.01	.85	1.91	.68	.93
1337	.944	.085	.02	.88	2.26	.83	.98	.935	.275	.06	.88	1.69	.62	.88
1407	.936	.086	.04	.95	2.04	.81	.98	.930	.229	.05	.95	1.68	.67	.90
1437	.916	.087	.08	1.08	1.72	.78	1.01	.910	.203	.09	1.08	1.46	.66	.94
1507	.874	.070	.10	1.17	1.53	.75	1.04	.872	.169	.09	1.17	1.34	.65	.96

Exchange coefficient and LE (combination) data for narrow and wide row sorghum, continued

	NARROW ROW							WIDE ROW						
Time	Rn	G	ΔT (°C)	Δe (mb)	K ($x10^3$)	LE (Combination)	LE (Lysimeter)	Rn	G	ΔT (°C)	Δe (mb)	K ($x10^3$)	LE (Combination)	LE (Lysimeter)
							August 6							
1537	.818	.064	.12	1.28	1.30	.69	.70	.819	.114	.11	1.28	1.22	.65	.59
1607	.732	.065	.18	.63	2.10	.55	.70	.740	.004	.16	.63	2.35	.62	.59
							August 7							
0839	.312	.041	.04	.33	1.79	.25	.298	.333	.059	.06	.78	0.79	.26	.34
0909	.390	.044	.08	.44	1.65	.30	.376	.411	.075	.09	1.61	0.47	.32	.369
0939	.411	.057	.07	.30	2.41	.30	.349	.431	.088	.09	1.88	0.42	.33	.329
1009	.466	.048	.04	.23	3.83	.37	.479	.485	.121	.07	.23	3.10	.30	.473
1039	.596	.068	.09	.49	2.26	.46	.531	.611	.132	.11	.49	2.00	.41	.526
1203	.846	.100	.12	.66	2.37	.65	.777	.858	.207	.15	.66	2.02	.56	.750
1233	.886	.096	.11	.72	2.34	.70	.803	.896	.285	.17	.72	1.73	.52	.723
1303	.953	.090	.08	.74	2.56	.79	.868	.951	.237	.19	.74	1.94	.60	.816
1333	.968	.102	.07	.86	2.25	.81	.946	.964	.253	.21	.86	1.67	.60	.84
1403	.586	.037	.03	.73	1.72	.52	.648	.592	.119	.23	.73	1.26	.38	.5
1433	.282	.015	.13	.37	1.38	.21	.44	.294	-.026	.18	.37	1.54	.24	.40
1503	.463	.065	.03	.61	1.48	.38	.505	.470	.091	.19	.61	1.21	.31	.50
1533	.591	.080	.04	.91	1.28	.49	.596	.620	.154	.23	.91	1.03	.39	.60
1603	.561	.063	.40	.39	1.80	.29	.70	.153	.084	.12	.39	0.35	.06	.698

(Table 3.1). Evapotranspiration accounted for an average of 88% and 89% of Rn in the narrow and wide rows respectively. Percent $^{LE}/_{Rn}$ was over 100 in the wide rows for August 25 and 26. This, in addition to the negative values of H towards the latter part of the growing season, confirm advective conditions reported in Chapter II. Average G for the wide rows was twice that for the narrow rows. There was a net gain of sensible heat in the wide rows while crops in the narrow rows lost sensible heat. Transpiration was higher in the narrow rows than in the wide rows.

The exchange coefficient, K, averaged 2600 cm^2/sec for the wide rows and 3320 cm^2/sec in the narrow rows for the days studied. Comparison of LE obtained by resistance, combination and lysimetric methods showed similar results in the morning (0700 to 1000 hours). In the afternoon, LE (combination) was lower than LE obtained by the other two methods (Figs. 3.4 and 3.5). In general, both resistance and combination methods underestimated LE. Early in the season, when the soil was dry and plant cover sparse, LE was much lower than potential LE on both plots. Later in the season, LE and potential LE on the plots were similar. Evapotranspiration rates in the narrow and wide rows were different only at the beginning of the season.

CHAPTER IV

NET CARBON EXCHANGE AND YIELD

Photosynthesis is a complex interaction of light, CO_2, water and mineral nutrients in the presence of chlorophyll and optimum temperature resulting in dry matter production. Many authors have reported on the relationship of mineral nutrient uptake and soil water to dry matter accumulation of sorghum (Vidal, Bono and Fauche, 1962; Herron, Grimes and Musick, 1963; Roy and Wright, 1973). The importance of light in photosynthesis was stressed in Chapter I. The bulk air is the source from which CO_2 diffuses to the leaf surface, through the stomata to the photosynthetic sites. The CO_2 supply in the air is supplemented by CO_2 released from the soil as a by-product of soil respiration. The diffusion processes leading to photosynthetic fixation of CO_2 is often expressed as:

$$P_s = F \frac{[CO_2]g - [CO_2]a}{r_a + r_s + r_m} \qquad (4.1)$$

where $[CO_2]g$ and $[CO_2]a$ are the concentration of carbon dioxide at the site of photosynthesis and in the air respectively; P_s is the net photosynthetic rate and F is the conversion factor from ppm to $g.cm^{-3}$. For most crops, the photosynthetic rate of individual leaves (Gaastra, 1959; Bierhuizen and Slatyer, 1964) as well as plant communities (Thomas and Hill, 1949) depends directly on CO_2 concentration of between 200 and 500 ppm. Higher dry matter production, better quality and earlier crop maturity have also been associated with the enrichment of CO_2 up to the saturation value of about 1000 ppm by weight. While it is difficult to increase CO_2 supply under field conditions, mild wind creates turbulence (mixing and renewing supply of

CO_2) and enhances photosynthesis (Waggoner, Moss and Hesketh, 1963).

Allen, Hanks, Aase and Gardner (1974) computed CO_2 uptake over irrigated wide-row sorghum by profile Bowen ratio method. They related CO_2 flux density to solar radiation and found slight midday depression in net photosynthetic rates. Denmead, Fritschen and Shaw (1962), working with corn planted at 100 cm row spacing, found that 75% of the net radiation was expended within the crop and estimated that closer row spacing could increase the energy available to photosynthesis by 15 to 20%.

Stickler and Laude (1960) and Shubeck and Lawrensen (1964-1968) observed increased yields in narrower rows and increased population for sorghum. In a similar experiment but comparing single row and double row methods of planting grain sorghum in Central Texas, Havelka (1965) reported that regular narrowing of rows was not significant in increasing grain yield of sorghum. However, the study showed yield increases of 400 to 700 pounds of grain per acre (350-650 kg/ha) by seeding in paired rows 30 cm apart, with 100 cm between the pairs as compared to single rows uniformly spaced.

In more recent experiments, Olson (1971) reported that grain sorghum yields from 102 cm rows with 175,000 plants per hectare and 51 cm rows with 250,000 plants per hectare were the same in adverse years but increased markedly with increasing population during the better growing seasons. He also noted that the decrease in the amount of water used by the lowest population was small. Scarsbrook and Doss (1973) working with corn, found that when plant population was constant, grain yield was higher with 51 cm row width than with 102 cm width.

The objectives of this chapter are:

1. to examine relationship between NCE and intercepted PAR and

2. to compare grain yield in the plots.

PROCEDURE

Two continuous flow systems, similar to that described by Brown (1969), were used for, alternately, sampling air from 3 field chambers. Each chamber is internally exchanged with outside air once a minute by 30-inch diameter fans; two small fans mix the air inside chamber. A pair of .625 cm (O.D) copper tubings sampled air from the intake and exhaust pipes. Sampled air from each chamber was passed through an infrared gas analyser and the difference in CO_2 content between the intake and exhaust samples (in parts per million) was recorded on a strip chart recorder (Newlett Packard 7100B).

Knowing the dimensions of the intake pipe and wind speed within the pipe allowed the determination of the total volume of air going into the chamber; hence, the net carbon exchange in the enclosed area could be calculated. The soil surface in the chambers was not covered. CO_2 flux from the soil surface was relatively constant (3 $mg.dm^{-2}.hr^{-1}$). Chambers containing 17 plants, were moved to new locations weekly to avoid any effects from the enclosure on plants.

RESULTS

NCE was plotted as a function of intercepted PAR (Figs. 4.1 and 4.2) for 5 days in July. The data points were best fitted into a linear equation:

$$\text{narrow rows} - Y = .45 + .49X \qquad (4.2)$$

$$\text{wide rows} - Y = 24.7 + .26X \qquad (4.3)$$

Fig. 4.1

Relationship between NCE and intercepted PAR in the narrow rows. Intercepted PAR in $nE.cm^{-2}sec^{-1}$

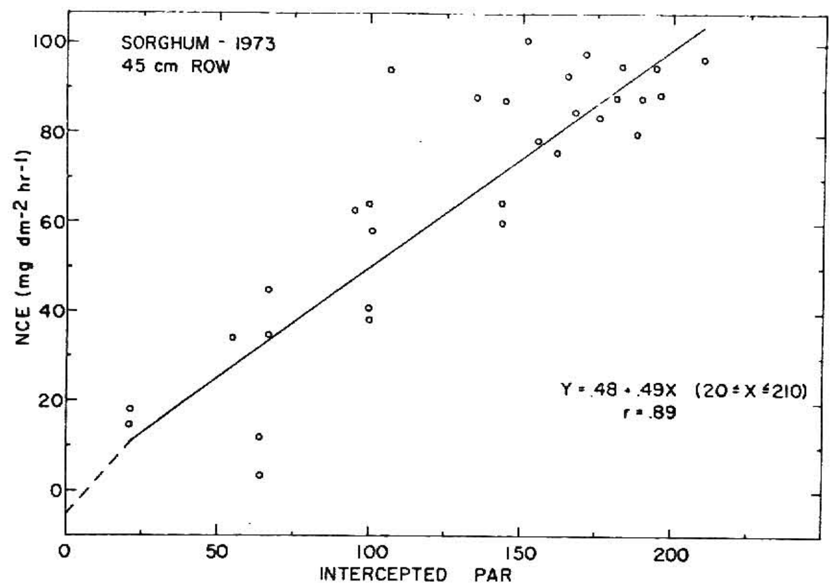
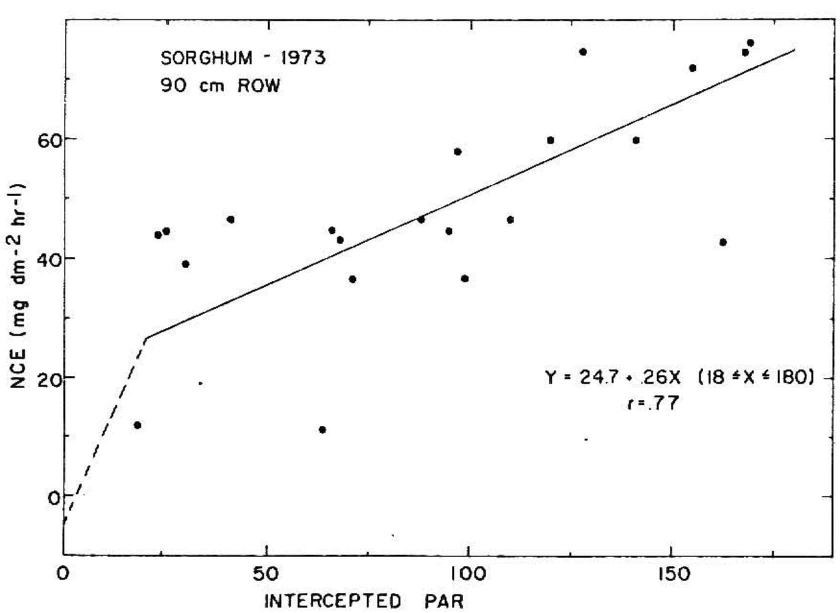


Fig. 4.2

Relationship between NCE and intercepted PAR in the wide rows. Intercepted PAR in $nE.cm^{-2}sec^{-1}$



where Y is NCE and X is intercepted PAR in $nE.cm^{-2}.sec^{-1}$. Both NCE and intercepted PAR values plotted, are hourly measurements taken between 1000 and 1400 hours on six days within crop stages 4 to 9 (Table 1.1). The straight lines obtained would be misleading if projected back to zero interception. The lines are meaningful within the regions spanned by the data points. At night, NCE fluctuates, but, generally, averaged about $-5\ mg.dm^{-2}.hr^{-1}$; therefore, curves (Fig. 4.1 and 4.2) were rounded to $-5\ mg.dm^{-2}.hr^{-1}$ when interception was zero. Their shape approximates that obtained by Bonner (1962) when he plotted the rate of photosynthesis as a function of incident light intensity for a single leaf.

Using equations (4.2) and (4.3), NCE would be about 30 $mg.dm^{-2}.hr^{-1}$ in the wide rows and only 10 $mg.dm^{-2}.hr^{-1}$ in the narrow rows at a light interception of 20 $nE.cm^{-2}.sec^{-1}$. It must be remembered that PAR interception was never the same on both plots at the same time. On July 16, intercepted PAR was almost twice as high in the narrow rows than in the wide rows (Chapter I; Fig. 1.6). PAR interception was similar on both plots by August 26. At this time, average PAR intercepted about midday was 187 $nE.cm^{-2}.sec^{-1}$ in the wide rows. The rate of increase in NCE with a unit increase in PAR interception, was almost twice as high in the narrow rows than in the wide rows.

The narrow rows intercepted more PAR (Fig. 1.6) and had higher NCE than the wide rows, especially, in the earlier dates during the growing season. It would, therefore, be expected that the narrow rows would give higher dry matter yield than the wide rows. The yield result (Table 4.1) shows average weight of 10 heads and total grain yield were slightly higher in the wide rows. The differences in average weight of heads and total grain yield were, however, not significant. It is to be noted that the

Table 4.1

Yield Data

	North Lysimeter (45 cm)	South Lysimeter (90 cm)
Average weight of 1000 seeds (gm) L.S.D.$_{.05}$ = 1.11	21.64	23.12
Average weight of 10 heads (gm)	393.57	401.73
Yield in kg/ha	4115	4178
Dry matter g/m^2	2224	1901

sorghum heads were out of the boot (grain filling) about July 30 (growth stage 6; Table 1.1). NCE, by this time, was only slightly higher in the narrow rows than in the wide rows. It would appear that the higher NCE in the narrow rows was used mainly in vegetative growth. The average weight of seeds was significantly higher in the wide row plot than in the narrow row plot (5% probability).

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Appendix

CLIMATIC DATA OF ASHLAND AGRONOMY FARM DURING THE GROWING SEASON (1973)

Date	R_S 16. day^{-1}	Wind Run km. day^{-1}	Rainfall cm
June 1	541	314	
2	433	426	
3	482	206	.64
4	140	269	1.32
5	676	270	3.43
6	737	166	.15
7	723	328	
8	687	377	
9	721	290	
10	700	291	
11	607	343	
12	456	209	*
13	523	77	2.94
14	403	277	
15	709	357	
16	588	262	
17	729	196	
18	719	410	
19	589	249	
20	725	135	
21	601	222	.07

Date	R_S ly. day^{-1}	Wind Run km. day^{-1}	Rainfall cm
June 22	732	43	*
23	701	163	
24	720	203	
25	479	383	.02
26	355	217	.09
27	741	228	.39
28	504	113	*
29	564	182	
30	666	214	
July 1	678	341	
2	629	484	.05
3	613	288	
4	707	209	
5	493	288	.74
6	703	341	
7	712	243	
8	708	251	
9	636	179	
10	679	240	.42
11	704	183	
12	714	301	
13	593	277	
14	390	208	3.75
15	624	116	
16	714	93	

Date	R_S ly. day^{-1}	Wind Run km. day^{-1}	Rainfall cm
July 16	714	93	
17	683	193	
18	573	138	3.80
19	454	249	
20	405	184	6.62
21	351	235	
22	278	166	
23	417	183	.51
24	264	195	.02
25	640	154	1.23
26	687	114	
27	609	169	
28	645	150	
29	602	134	
30	639	193	
31	637	163	
August 1	632	121	
2	651	90	
3	643	124	
4	641	219	
5	-	251	
6	-	434	
7	506	198	*
8	534	216	2.45
9	532	135	

Date	R_S ly. day^{-1}	Wind Run km. day^{-1}	Rainfall cm
August 10	567	105	.07
11	552	175	
12	547	217	
13	535	230	.91
14	626	80	
15	443	164	1.08
16	612	109	
17	607	195	
18	589	220	
19	553	185	
20	578	145	
21	585	222	
22	541	364	
23	538	212	.07
24	292	204	
25	558	286	
26	570	336	
27	525	285	
28	525	301	*
29	516	172	
30	436	286	
31	284	378	.37
September 1	274	438	
2	458	409	
3	343		1.96

Date	R_S ly. day^{-1}	Wind Run km. day^{-1}	Rainfall cm
September 4	392		
5	452		
6	525		
7	99		
8	211		1.72
9	460		1.84

*Irrigation

THE MICROCLIMATE OF NARROW AND WIDE ROW SORGHUM WITH EQUAL PLANT DENSITY

by

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B.Sc., Ahmadu Bello University, 1972

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
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1974

ABSTRACT

The study was designed to (1) compare the radiation and energy balance of narrow- (45 cm) and wide-row (90 cm) sorghum and (2) accumulate microclimatic and plant data for narrow- and wide-row sorghum of equal plant density. Measurements were made to facilitate the comparison of the planting patterns with regard to:

1. the interception of photosynthetic active radiation (PAR)
2. the partition of net radiation into the component terms of the energy balance equation, and
3. the spectral reflectance within 400 to 750 nm wavelengths.

Temperature, vapor pressure, stomatal resistance, and leaf water potential measurements were made along the direction of the prevailing wind (N-S) so transfer of advective energy (in the form of large scale, border or within-row advection) could be detected. Evapotranspiration (LE), determined with lysimeters, was compared with LE estimated by resistance and combination methods.

The narrow-row canopy reflected and intercepted more PAR than the wide rows. More PAR was transmitted through the wide-row canopy. Reflected PAR and near infrared radiation (NIR) were 5% and 41.7%, respectively, in the narrow rows as compared to 4.7% and 28.5% in the wide rows. Percent PAR intercepted during July was 92 for the narrow rows and 77 for the wide rows. Total radiation intercepted during July averaged 70.6% and 59% in the narrow rows and wide rows, respectively. Average seasonal albedo was 0.20 for the narrow rows and 0.18 for the wide rows. Since LAI and climatic conditions were similar for both plots throughout the growing season, the differences

in albedo are apparently the result of the differences in cropping pattern and consequently, differences in percentage plant cover. Although albedo was higher in the narrow rows, reflectance in the 400 to 500 nm and 600 to 650 nm wavebands was about the same for both plots.

Temperature and stomatal resistance decreased with increasing distance in the leeward direction (downwind). Leaf water potential and vapor pressure, however, increased with increasing distance in the leeward direction. These facts, in addition to temperature inversions above the crop (warmer air layer above the crop) confirm earlier reports of large scale advection towards the latter stages of crop development at this location. Also near maturity, a tunnel of air moving below the level of maximum leaf concentration (35-80 cm) constituted a sink for water vapor moving in from transpiring leaves and the soil surface.

There was no significant difference in net radiation, Rn, above the plots. LE accounted for an average of 88% and 89% of Rn in the narrow and wide rows, respectively. Average soil heat flux for the wide rows was twice that for the narrow rows. There was a net gain of sensible heat in the wide rows as opposed to a net loss by the narrow row canopy. Transpiration was higher in the narrow rows than in the wide rows. Actual evapotranspiration equaled potential evapotranspiration after the canopy attained a leaf area index of about 3.5. Comparison of LE obtained by resistance, combination, and lysimetric methods showed similar results in the morning (0700 to 1000 hours). In the afternoon, LE (combination) was lower than LE obtained by the other two methods. In general, both resistance and combination methods underestimated LE

The higher PAR interception and greater net carbon exchange by the narrow row canopy, especially in the early part of the growing season, was not reflected in grain yield. Average weight of heads and total grain yield, though slightly higher in the wide row plot, were not significantly different in the two plots. The average weight of seeds was significantly higher in the wide row plot than in the narrow row plot.